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DRAFT
TREATABILITY STUDY IN SUPPORT OF
REMEDATION BY NATURAL ATTENUATION
BUILDING 1212

at

FAIRCHILD AIR FORCE BASE
SPOKANE, WASHINGTON

January 1997

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

AND

92ND CES/CEVR
FAIRCHILD AIR FORCE BASE
SPOKANE, WASHINGTON

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EXECUTIVE SUMMARY

This report presents the results of a treatability study (TS) performed by Parsons Engineering Science, Inc. (Parsons ES) at Building 1212, Fairchild Air Force Base, Washington to evaluate remediation by natural attenuation (RNA) of dissolved fuel-hydrocarbons in the shallow groundwater. The TS focused on the fate and transport of dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) in the shallow groundwater system at the site. Residual light nonaqueous-phase liquid (LNAPL) present within the vadose zone and phreatic soils serves as a continuing source for the dissolved groundwater contamination. There is no evidence of mobile LNAPL at this site. The site history also is summarized in this report. No previous investigations have been conducted at the Building 1212 site to determine the nature and extent of soil and groundwater contamination.

Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps for the Building 1212 site provides strong qualitative evidence of biodegradation of dissolved BTEX compounds. These geochemical data strongly suggest that biodegradation of dissolved fuel hydrocarbons is occurring at the site via aerobic respiration and the anaerobic processes of denitrification, sulfate reduction, and methanogenesis. Patterns observed in the distribution of hydrocarbons, electron acceptors, and biodegradation byproducts further indicate that biodegradation is reducing dissolved BTEX concentrations in site groundwater.

An important component of this study was an assessment of the potential for contamination in groundwater to migrate from the source areas to potential receptors. The Bioplume II numerical model was used to evaluate the fate and transport of dissolved BTEX in the shallow groundwater under the influence of advection, dispersion, sorption, and biodegradation. Input parameters for the Bioplume II model were obtained from data collected by Parsons ES. Model parameters that were not measured at the site were estimated using reasonable literature values.

The results of this demonstration suggest that RNA of BTEX is occurring at Building 1212, furthermore, the estimated rates of biodegradation, when coupled with sorption, dispersion, and dilution, should be sufficient to reduce and maintain dissolved BTEX

concentrations to levels below current regulatory guidelines long before potential downgradient receptors could be adversely affected. The Air Force, therefore, recommends implementation of RNA and LTM with institutional controls. Conservative modeling suggests that under current conditions, the dissolved BTEX will not migrate beyond the current plume extent and dissolved BTEX contamination throughout the plume would be reduced to concentrations below regulatory levels within 34 years. Building 1212 was recently added into the base explosive safety zone. The site will be vacated and all site access will be controlled by Fairchild AFB security. Therefore, future site activities will be more limited and the risk to any base personnel would be minimal provided institutional controls for soil and groundwater are maintained. Institutional controls such as restrictions on shallow groundwater use at the site would prevent completion of exposure pathways until RNA is complete.

To verify the Bioplume II model predictions, and to ensure that the selected technologies are meeting objectives, the Air Force recommends using 9 LTM wells and 4 sentry wells to monitor the long-term migration and degradation of the dissolved BTEX plume. In addition to analyses used to verify the effectiveness of RNA, the groundwater samples should be analyzed for BTEX compounds by US Environmental Protection Agency (USEPA) Method SW8020. If data collected under the LTM program indicate that the selected remedial system is not sufficient to reduce BTEX concentrations at downgradient sentry well locations to levels considered protective of human health and the environment, additional corrective actions may be required to remediate groundwater at the site.

SECTION 1

INTRODUCTION

This report was prepared by Parsons Engineering Science, Inc. [Parsons ES, formerly Engineering-Science Inc. (ES)] and presents the results of a treatability study (TS) conducted to evaluate remediation by natural attenuation (RNA) for remediation of fuel-hydrocarbon contaminated groundwater at the Building 1212 Facility, Fairchild Air Force Base (AFB), Spokane, Washington. The main emphasis of the work described herein was to evaluate the effectiveness of natural attenuation mechanisms to reduce dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations in groundwater to levels that do not exceed federal and state groundwater protection standards.

As used in this report, RNA refers to a management strategy that relies on natural attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The United States Environmental Protection Agency (USEPA) Office of Research and Development (ORD) and Office of Solid Waste and Emergency Response (OSWER) define natural attenuation as (Wilson, 1996):

The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

As suggested by this definition, mechanisms for natural attenuation of BTEX include advection, dispersion, dilution from recharge, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. Contaminant destruction occurs through biodegradation when indigenous microorganisms work to bring about a reduction in the total mass of contamination

in the subsurface without the addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

1.1 SCOPE AND OBJECTIVES

Parsons ES, in conjunction with researchers from the USEPA National Risk Management Research Laboratory (NRMRL) Subsurface Protection and Remediation Division, was retained by the United States Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division to conduct site characterization and groundwater modeling to evaluate the scientific defensibility of RNA with long-term monitoring (LTM) as a component of remediation for contaminated groundwater at Building 1212.

There were two primary objectives for this project:

- Determine whether natural attenuation processes for fuel hydrocarbons are occurring in groundwater at the site, and if so,
- Investigate the use of these processes to minimize the expansion of the contaminant plume and to ensure that federal and state groundwater protection standards will be met at a downgradient point of compliance (POC).

These objectives were accomplished by:

- Reviewing previously reported hydrogeologic, soil quality, and groundwater quality data for the site;
- Conducting supplemental site characterization activities to determine the nature and extent of soil and groundwater contamination;
- Collecting geochemical data in support of RNA;
- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants;
- Evaluating site-specific data to determine whether natural processes of contaminant attenuation and destruction are occurring in groundwater at the site;

- Using the Bioplume II numerical model to simulate the fate and transport of BTEX in groundwater under the influence of biodegradation, advection, dispersion, and adsorption;
- Evaluating a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate and transport scenarios;
- Determining if natural processes are sufficient to reduce dissolved BTEX plume expansion so that groundwater quality standards can be met at a downgradient POC;
- Developing remedial action objectives (RAOs) and reviewing available remedial technologies;
- Using the results of modeling to recommend the most appropriate remedial option based on specific effectiveness, implementability, and cost criteria; and
- Providing a LTM plan that includes LTM and POC well locations and a sampling and analysis plan.

The field work conducted under this program was oriented toward collecting supplementary hydrogeologic and chemical data necessary to document and model natural attenuation mechanisms currently operating at the site. During May 1996, site characterization activities included the collection of soil samples and placement of monitoring wells with a hollow-stem auger (HSA) drill rig; use of Geoprobe® direct-push technology for groundwater grab sample collection; aquifer testing; and sampling and analysis of groundwater from new groundwater monitoring wells. Many of the hydrogeologic data necessary to evaluate RNA were available from previous investigations conducted at this site, at other sites with similar characteristics, or in technical literature.

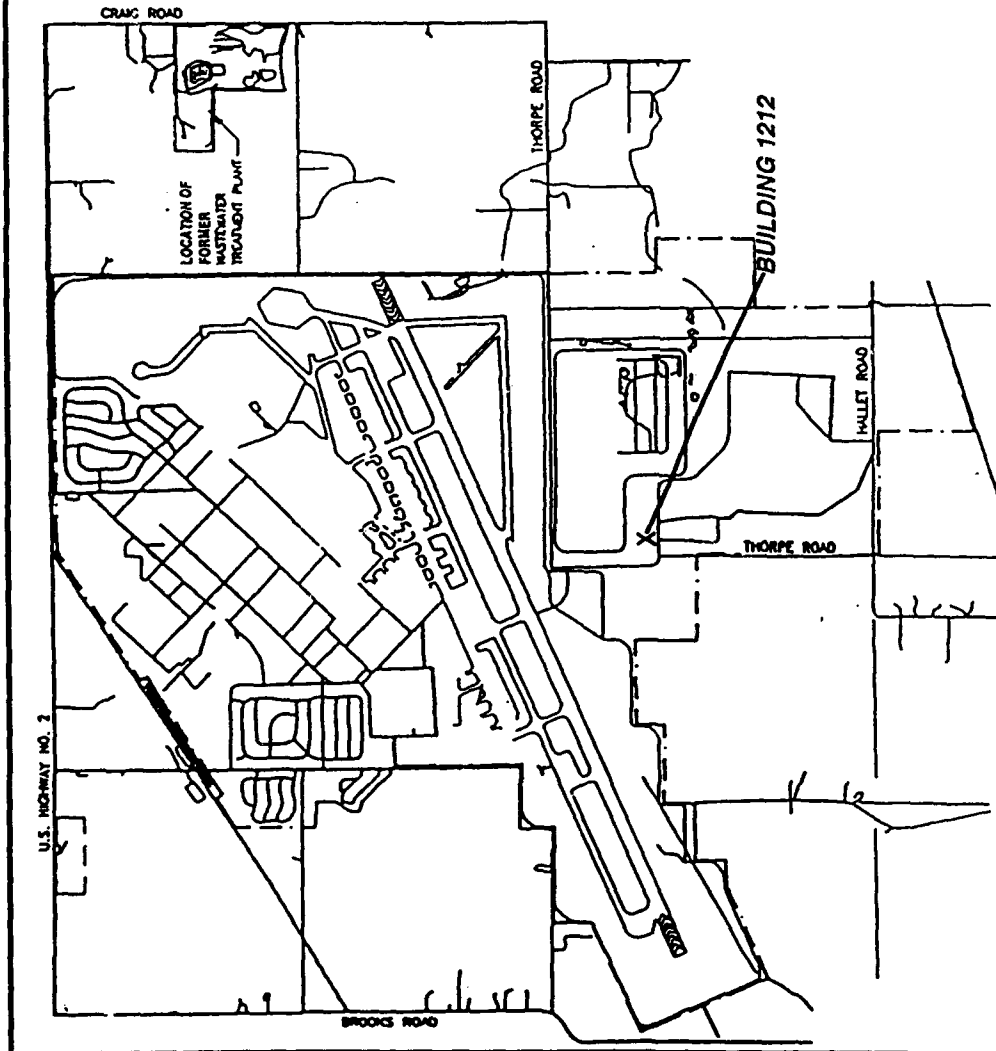
Site-specific data were used to develop a fate and transport model for the site using the groundwater flow and solute transport model Bioplume II to evaluate processes of natural attenuation. The Bioplume II model was used to simulate the movement of dissolved BTEX in the shallow saturated zone under the influence of biodegradation, advection, dispersion, and sorption. Results of the model were used to assess the effectiveness of natural attenuation mechanisms.

This report contains nine sections, including this introduction, and five appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil and groundwater contamination and the geochemistry of soil and groundwater at the site. Section 5 describes the Bioplume II model and design of the conceptual model for the site; lists model assumptions and input parameters; and describes sensitivity analysis, model output, and the results of the Bioplume II modeling. Section 6 presents a comparative analysis of remediation alternatives. Section 7 presents the recommended LTM plan for the site. Section 8 presents the conclusions of this work and provides recommendations for further work at the site. Section 9 lists the references used to develop this document. Appendix A contains geologic borehole logs, monitoring well installation records, and slug test results. Appendix B presents soil and groundwater analytical results. Appendix C contains calculations and model input parameters. Appendix D contains Bioplume II model input and output in ASCII format on a diskette. Appendix E contains cost calculation estimates for evaluated remediation systems.

1.2 FACILITY BACKGROUND

Fairchild AFB occupies an area of approximately 4,300 acres 12 miles west of Spokane, Washington. The Base is divided roughly in half by the main northeast/southwest runway (Figure 1.1). Aircraft operational facilities, approximately 1,600 Base housing units, an elementary school, a hospital, and support facilities for on-Base residents lie north of the runway. The air traffic control tower, weapons storage area, and survival training school facility lie to the south of the runway [Halliburton NUS (HNUS), 1993a].

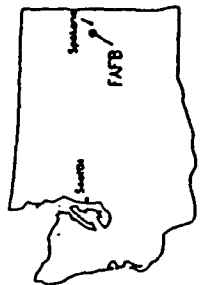
The Base was established in 1942 as an Army repair depot and transferred to the Strategic Air Command (SAC) in 1947. In 1992, Base control was transferred to the Air Combat Command (ACC). Currently, the Base is operated by the Air Mobility Command (AMC) and serves as host to the 92nd Air Refueling Wing. The Base also is the current home of the



LEGEND
 ○ - SURFACE WATER FEATURE
 --- BASE BOUNDARY



0 1000 2000 3000 4000
 SCALE IN FEET



Key Plan

FIGURE 1.1

SITE LOCATION

Building 1212
 Remediation By Natural Attenuation TS
 Fairchild AFB, Washington

**PARSONS
 ENGINEERING SCIENCE, INC.**
 Denver, Colorado

141st Air Refueling Wing of the Washington Air National Guard (WANG), aircraft operational facilities, a weapons storage area, and a survival training school. Base operations employ approximately 5,000 civilian and military personnel (ES, 1994).

Building 1212 is associated with the US Air Force Survival Training School located on the south side of the Base. Building 1212 is currently used for vehicle maintenance and fueling. A portion of the building is also used for classroom activities associated with the survival training school (Figure 1.2). In October 1995, two 3,000-gallon gasoline underground storage tanks (USTs) were removed from beneath the southern end of the asphalt/pavement area immediately south of Building 1212 by Budinger and Associates (1995). The two tanks were replaced with one 4,000-gallon tank that will be removed when the Building 1212 facility is relocated. Approximately 40 cubic yards of fuel-contaminated soil was excavated and replaced with clean soil. Prior to the removal of the gasoline USTs, a heating oil tank was excavated and removed from the area adjacent to the southeastern corner of Building 1212. A large stockpile of overburden from this tank excavation was removed from the site, and the excavation was backfilled with clean soil.

No documented spills have occurred at Building 1212, but field observations made by Budinger and Associates personnel during the October 1995 UST removal effort suggest that buried fuel distribution lines from the tanks to the dispensers may have leaked for an unknown period of time. Budinger and Associates (1995) reported grossly contaminated soils surrounding some of the threaded connections from the product supply piping and dispenser piping. It also was reported that some of the welds on both tanks may have leaked.

Soil contamination from the two gasoline USTs was reported by Budinger and Associates (1995) between 3 to 9 feet below ground surface (bgs) in the eastern end of the gasoline tank removal excavation. The occurrence and magnitude of contamination appeared variable. At the western end of the excavation some slightly contaminated soils were encountered. Prior to this RNA investigation, groundwater contamination had not been investigated at Building 1212.

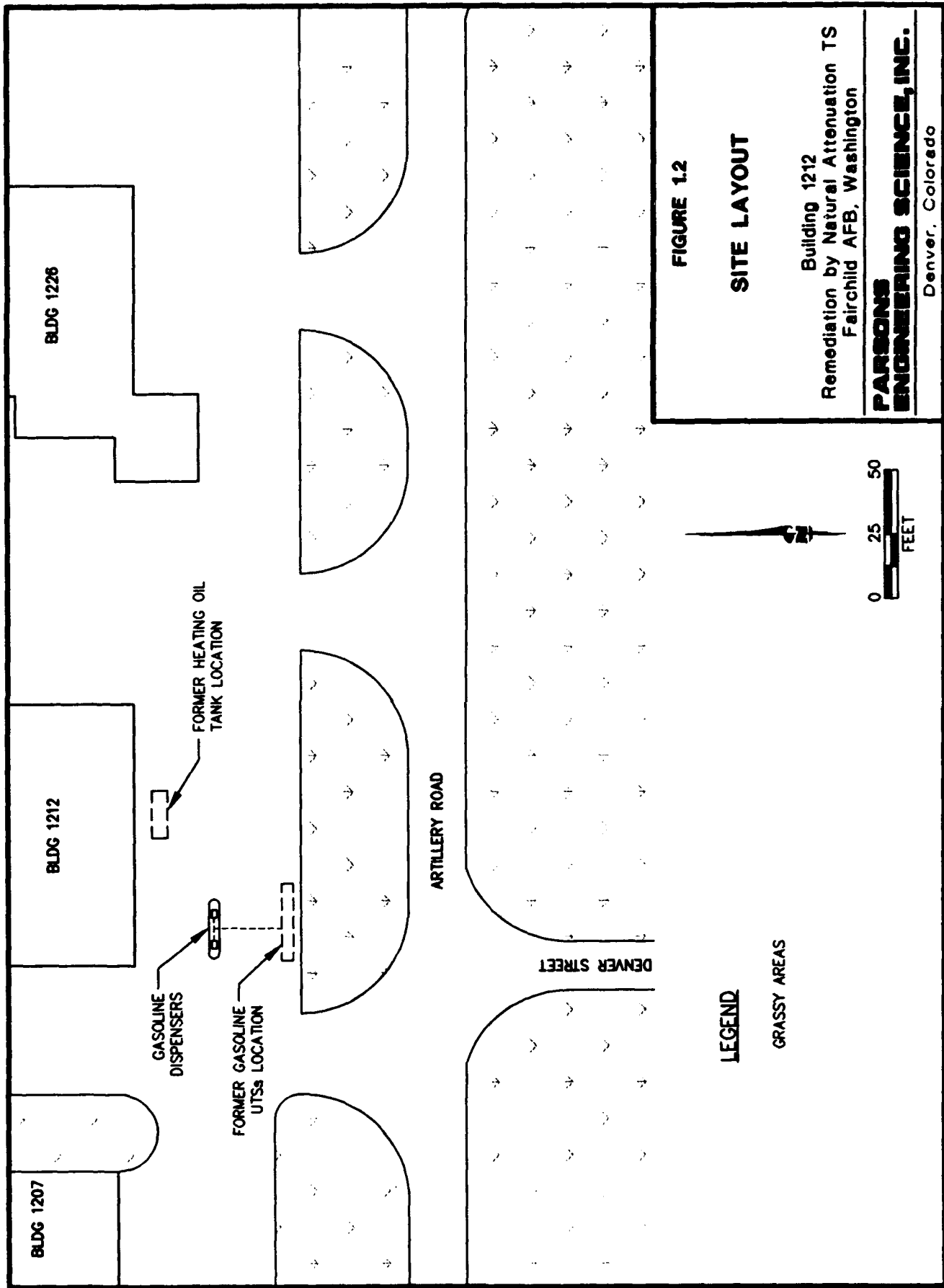


FIGURE 1.2

SITE LAYOUT

Building 1212
Remediation by Natural Attenuation TS
Fairchild AFB, Washington

**PARSONS
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Denver, Colorado

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods used by Parsons ES personnel to collect site-specific data at Building 1212, Fairchild AFB, Washington. To meet the requirements of the RNA demonstration, data were collected in one site characterization event. The site characterization was performed in May 1996, and consisted of monitoring well installation, soil and groundwater sampling, and aquifer testing to evaluate near-surface geology and geochemistry, aquifer properties, and the extent of soil and groundwater contamination for the area surrounding Building 1212. Well installation and soil sampling were accomplished during this investigation using HSA drilling in conjunction with split-barrel sampling. Groundwater sampling was accomplished during this investigation at newly installed monitoring wells and at temporary Geoprobe® monitoring points. Previously collected data were integrated with data collected under this program to develop the conceptual site model and to aid interpretation of the physical setting (Section 3) and contaminant distribution (Section 4).

The following sections describe the procedures that were followed when collecting site-specific data. Additional details regarding investigative activities are presented in the work plan (Parsons ES, 1996).

2.1 DRILLING, SOIL SAMPLING, AND MONITORING WELL INSTALLATION

Drilling-related field work occurred between May 18 and May 22, 1996, and consisted of soil sampling and groundwater monitoring well installation. Thirteen groundwater monitoring wells were installed at 12 locations to assist in the characterization of the shallow groundwater flow system at Building 1212. These wells were identified as MW-1(S), MW-1(D), MW-2, MW-3, MW-4, MW-5, MW-6, MW-7, MW-8, MW-9, MW-10, MW-11, and MW-12. The new wells were installed in the locations shown on Figure 2.1. Table 2.2 presents monitoring well completion details. A nested well pair [MW-1(S) and

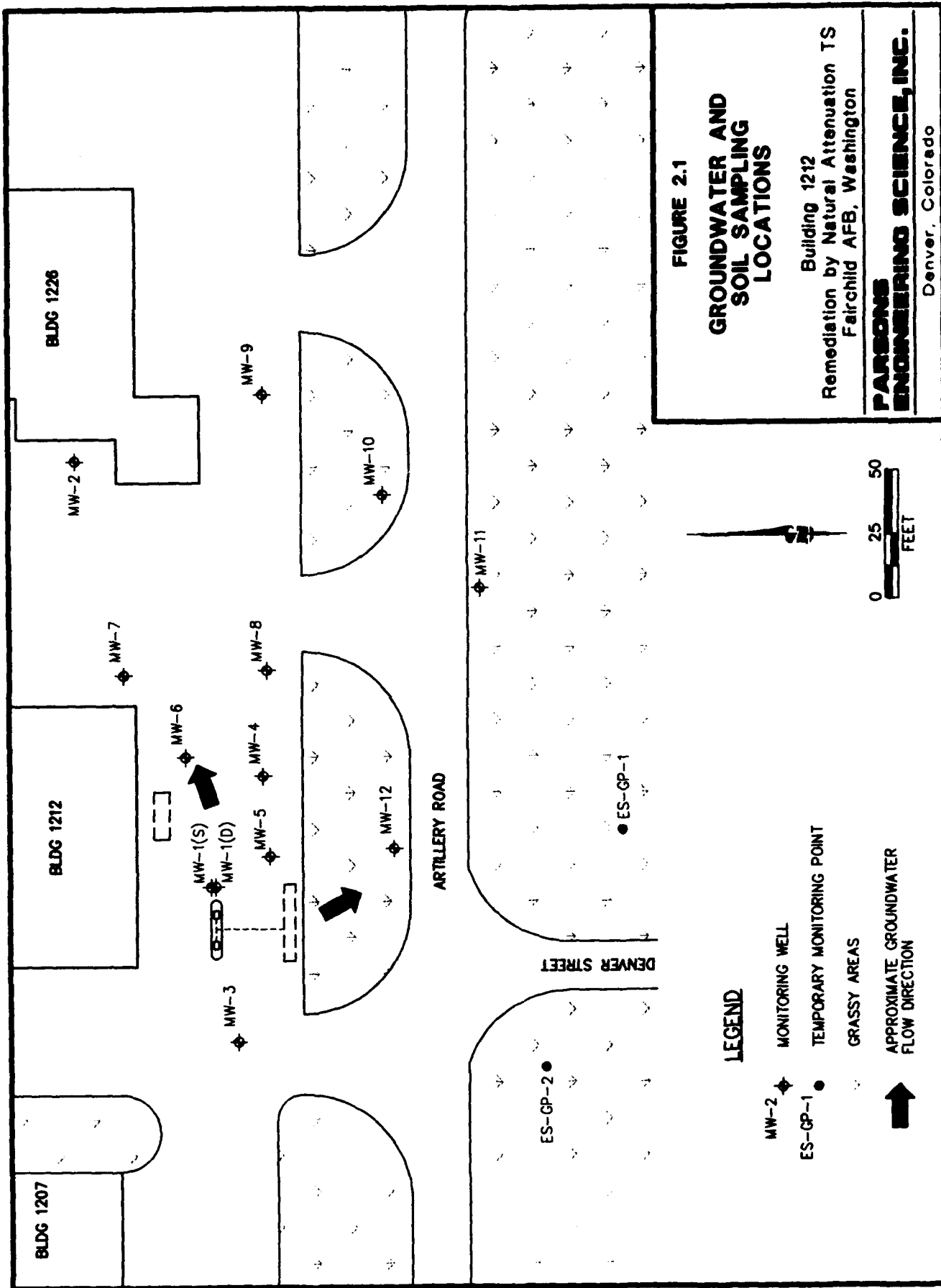


TABLE 2.1
SUMMARY OF WELL INSTALLATION DETAILS
BUILDING 1212
REMEDICATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Well Identification	Installation Date	Northing (feet)	Easting (feet)	Total Well		Borehole Diameter (inches)	Casing Diameter (inches)	Slot Size (inch)	Screen Interval (feet bgs)	Approx. Ground Surface (feet msl) ^v	Top of Casing Elevation (feet msl)
				Borehole Depth (feet bgs) ^v	Completion Depth (feet bgs)						
MW-1(S)	5/18/96	5085.5	5620.8	14.5	14.0	8	2	0.01	6.0-14.0	2432.72	2432.50
MW-1(D)	5/18/96	5083.8	5620.8	24.0	24.0	8	2	0.01	19.0-24.0	2432.73	2432.45
MW-2	5/18/96	5137.6	5787.3	26.5	20.0	8	2	0.01	10.0-20.0	2432.81	2432.50
MW-3	5/20/96	5075.2	5560.2	21.5	17.5	8	2	0.01	7.0-17.0	2432.26	2432.03
MW-4	5/20/96	5065.4	5664.1	22.5	18.5	8	2	0.01	8.0-18.0	2432.26	2431.86
MW-5	5/20/96	5062.7	5632.6	20.5	18.5	8	2	0.01	8.0-18.0	2432.33	2432.12
MW-6	5/20/96	5095.2	5671.5	24.0	18.5	8	2	0.01	8.0-18.0	2432.80	2432.53
MW-7	5/21/96	5118.8	5703.6	19.0	17.5	8	2	0.01	7.0-17.0	2432.69	2432.30
MW-8	5/21/96	5063.8	5705.4	21.0	16.5	8	2	0.01	6.0-16.0	2431.97	2431.70
MW-9	5/21/96	5065.0	5813.1	16.0	15.0	8	2	0.01	5.0-15.0	2431.91	2431.74
MW-10	5/21/96	5018.6	5773.8	17.0	16.0	8	2	0.01	5.5-15.5	2431.22	2430.86
MW-11	5/21/96	4981.2	5737.2	17.5	16.5	8	2	0.01	6.0-16.0	2430.65	2430.36
MW-12	5/22/96	5014.5	5635.6	21.0	16.5	8	2	0.01	6.0-16.0	2431.26	2430.79

^v feet bgs = Feet below ground surface.

^v feet msl = Feet above mean sea level.

MW-1(D)] was installed within the source area for vertical resolution of dissolved contaminant distribution at the site. The nested wells were installed adjacent to each other, with one well (designated by the suffix "S") screened near the water table surface, and with the deeper well (designated by the suffix "D") screened at the base of the unconsolidated shallow aquifer immediately above the bedrock. The well locations were selected to provide the hydrogeologic data necessary for successful implementation of the Bioplume II model and to support the RNA demonstration. These activities were performed according to the procedures described in the work plan (Parsons ES, 1996) and in the following sections.

2.1.1 Well Drilling and Soil Sampling Procedures

This section describes the procedures that were used for drilling and installation of the 13 monitoring wells. All soil samples and monitoring wells were installed in accordance with general procedures outlined in the AFCEE intrinsic remediation protocol document (Weidemeier *et al.*, 1995).

2.1.1.1 Pre-Drilling Activities

All subsurface utility lines or other man-made subsurface features were located, and proposed drilling locations were cleared and approved by the Base prior to any drilling activities. Water used in drilling, equipment cleaning, or grouting was obtained from a potable water supply provided by the drilling subcontractor. Suitability of the water source was verified by field personnel.

2.1.1.2 Equipment Decontamination Procedures

Prior to arriving at the site, and between each drilling location, the augers, drilling rods, bits, samplers, tools, and other downhole equipment were decontaminated using a high-pressure, steam/hot water wash. Only potable water was used for decontamination.

During drilling operations, the drill rig, augers, and any downhole drilling equipment were decontaminated at a site decontamination pad. Water from the steam/hot water wash operation was allowed to collect in the decontamination pad until full. After treatment, water was stored in a 1,200-gallon holding tank located on site. Water from the holding tank was released into an onsite sanitary sewer following analytical screening

for compliance with the Base sanitary sewer discharge permit. Precautions were taken to minimize any impact to the area surrounding the decontamination pad that might result from the decontamination operations.

Prior to use and between each sampling event, all soil sampling tools were cleaned onsite with a clean water/Alconox[®] detergent mix, clean water rinse, and a distilled water rinse. All decontamination activities were conducted in a manner so that the excess water was controlled and not allowed to flow into any open borehole.

Fuel, lubricants, and other similar substances were handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials were factory sealed and were not stored near or in areas that could be affected by these substances.

2.1.1.3 Drilling and Soil Sampling

Drilling was accomplished by using the HSA method. The borings were drilled and sampled to the total depth of the borehole (Table 2.1). At the nested monitoring well location (MW-1), only the deeper well was logged and sampled. In many instances, refusal at the top of the basalt bedrock prevented collection of representative samples from the bottom of the borehole. A final borehole diameter of at least 8 inches was used for the installation of wells with a 2-inch inside-diameter (ID) casing.

Soil samples were obtained using a 2.5-inch-ID split-barrel sampling device (i.e., a split spoon). At borehole MW-1, samples were collected continuously over the full depth of the soil borehole. At all other boreholes, samples were collected in alternating 2-foot intervals or at the field geologist's discretion. Soil samples for logging and field testing were collected in unlined split-barrel samplers; soil samples for laboratory analysis were collected in 6-inch brass liners placed in the split-barrel sampler prior to sampling. After sample collection, the liners were capped with Teflon[®] tape and plastic caps. In addition, a representative portion of each soil sample was placed in a clean glass jar and capped with aluminum foil for photoionization detector (PID) headspace measurements for volatile organic compounds (VOCs). Soil remaining in the spoon was used for lithologic and stratigraphic logging. Jars containing soil samples collected for the headspace procedure were quickly sealed and held for 15 minutes at an ambient temperature of

65 degrees Fahrenheit (°F) or greater. Semiquantitative measurements were made by puncturing the foil seal with the PID probe and reading the concentration of the headspace gases. The PID relates the concentration of total VOCs in the sample to an isobutylene calibration standard. The PID also was used to monitor the worker breathing zone during sampling activities.

The Parsons ES field hydrogeologist observed drilling and well installation activities and maintained a detailed descriptive log of subsurface materials recovered. Final geologic boring logs are presented in Appendix A. These logs contain:

- Sampled intervals (top and bottom depth);
- Presence or absence of contamination based on odor, staining, and/or PID readings;
- Soil description, including color, major textural constituents, minor constituents, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, and any other significant observations; and,
- Lithologic contacts, with the depth of lithologic contacts and/or significant textural changes recorded to the nearest 0.1 foot (1 inch).

At several borehole locations, one soil sample from the vicinity of the water table was selected for laboratory analysis. Soil samples were collected from boreholes MW-1, MW-3, MW-4, MW-5, MW-6, MW-7, MW-8, and MW-12. Where no elevated PID headspace readings were encountered, samples were collected from immediately above and/or immediately below the water table. Where PID readings were elevated, one of the samples submitted for laboratory analysis was from the interval giving the highest reading. Analytical sample containers and appropriate container lids were provided by Envirotech, Inc. Personnel from Parsons ES participated in soil sampling. Personnel from the USEPA NRMRL were responsible for sample analysis.

The sample containers were filled completely to minimize headspace. The containers were sealed with Teflon[®] tape and lids were placed over the tape and tightly closed. A sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

- Sample identification;
- Sample depth;

- Sampling date; and,
- Sample collector's initials.

After the samples were sealed and labeled, they were placed in a cooler with ice and held for transport to the USEPA laboratory. The VOC analysis for soil samples included the BTEX compounds and total fuel carbon.

All soil cuttings were initially stored in a 10-cubic-yard roll-off waste container near the east side of Building 1212. These soils at the site were transferred to a soil disposal subcontractor for disposal following the completion of drilling activities.

2.1.2 Monitoring Well Installation

Groundwater monitoring wells were installed in 13 borings at 12 locations under this program. Well construction details were noted on a Monitoring Well Installation Record form and are summarized on Table 2.1. This information became part of the permanent field record for the site. Monitoring well installation forms and well completion diagrams for Building 1212 wells are presented in Appendix A. The field hydrogeologist verified and recorded the boring depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus between the casing and borehole wall. All lengths and depths were measured to the nearest 0.1 foot. Detailed well installation procedures are described in the following paragraphs.

2.1.2.1 Well Materials Decontamination

All well completion materials were factory sealed, and were inspected by the field hydrogeologist and determined to be clean and acceptable prior to use. Pre-packaged sand, bentonite, and concrete mix were used in well construction, and the bags were inspected for possible external contamination before use. Materials that could not be cleaned to the satisfaction of the field hydrogeologist were not used.

2.1.2.2 Well Casing

Upon completion of drilling to the proper borehole termination depth, a monitoring well casing was installed. Blank well casing consisted of Schedule 40 polyvinyl chloride (PVC) with an ID of 2 inches. All well casing sections were flush threaded, and glued

joints were not used. The casing at each well was fitted with a lockable top cap constructed from rubber and PVC.

2.1.2.3 Well Screen

Well screens consisted of flush-threaded, Schedule 40 PVC with an ID of 2 inches. The screens were 10 feet in length and factory slotted with 0.010-inch openings. Each shallow well was screened so that seasonal fluctuations of the water table can be measured and so that mobile light non-aqueous-phase liquid (LNAPL) can be detected (if present). For the nested well pair, the deep well was screened with a 5-foot screen at the base of the unconsolidated surficial aquifer at approximately 5 feet below the bottom of the shallow screen. Well screen positions were selected by the field hydrogeologist after consideration was given to the geology and hydraulic characteristics of the stratum in which the wells were screened.

2.1.2.4 Sand Filter Pack and Annular Sealant

A graded sand filter was placed around the screened interval from the bottom of the casing to approximately 2 feet above the top of the screen. Number 20-40 Colorado silica sand was used for the sand filter pack. Placement of a sand filter pack around well MW-9 was compromised from heaving formation sands being forced into the HSA by hydrostatic pressures. Approximately 10 gallons of potable water was used to install the sand filter packs in this well. The addition of water into the well bore during well installation increases the downward pressure head within the bore, helping to offset the hydraulic pressure created by the formation at depth, and reducing the heave of formation sands within the well bore. The heaving formation soil in well MW-9 was a coarse sand that did not contribute to the breaching or clogging of well screens, and well development (described in Section 2.1.4) proceeded without incident. Additional groundwater was removed from well MW-9 during development to compensate for the addition of potable water during well installation.

A seal of sodium bentonite chips was placed above the sand filter pack in all wells. The filter pack seal was a minimum of 2 feet thick and, where placed above the water table, was hydrated in place with potable water. In all wells at Building 1212, the remainder of the annular seal up to the surface seal also consisted of hydrated bentonite

chips. This seal was selected because the water table was shallow enough to omit the use of bentonite grout. A 0.5-foot gravel layer was placed on top of the bentonite seal at a depth of 0.5 to 1-foot bgs.

2.1.2.5 Protective Cover

For all wells, protective 8-inch-diameter flush-mount casings were set into a 2-foot-square concrete pad to a depth of 0.5 to 1.0 foot bgs. The casings were cemented in place with the bottom anchored in a 6-inch thick gravel pad in order to facilitate drainage of excess storm water penetrating the protective casing. The tops of the covers were placed approximately at ground surface. Well identifications were permanently inscribed on the well casing and protective cover.

2.1.3 Well Development

Prior to sampling, newly installed monitoring wells were developed. Typically, well development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen.

Well development was accomplished using a two-stage or peristaltic pump. Wherever possible the two-stage pump was used for development; however, because of the fine-grained aquifer matrix, the groundwater recharge rate into several wells was less than the lowest possible flow rate from the two-stage pump. To account for the slow recharge, a peristaltic pump was used in low flow wells. Surging of the surrounding formation was accomplished by a rapid upward/downward movement of the two-stage pump or a dedicated high-density polyethylene (HDPE) bailer, creating agitation in the casing that helped remove fine-grained materials from the monitoring well. Development was continued until 10 casing volumes of groundwater were removed from the well and the groundwater pH, temperature, conductivity, and dissolved oxygen concentrations had stabilized. Water characteristics such as appearance and odor were recorded by the Parsons ES field both prior to development and after development.

All well development waters were collected in 5-gallon buckets transported to the on-site 1,200-gallon wastewater storage tank for future disposal. All downhole equipment associated with the two-stage pump was decontaminated by soaking and pumping an

Alconox[®] detergent and potable water solution followed by potable water. Peristaltic pump tubing was dedicated to each well.

2.2 GROUNDWATER SAMPLING

This section describes the procedures used for collecting groundwater samples. In order to maintain a high degree of quality control (QC) during this sampling event, the procedures described in the site work plan (Parsons ES, 1996) and summarized in this section were followed.

Groundwater sampling occurred on May 29 and 30, 1996, and consisted of collecting groundwater samples from the 13 newly installed monitoring wells and 2 Geoprobe[®] locations, ES-GP-1 and ES-GP-2 (Figure 2.1). Groundwater sampling forms were used to document the specific details of the sampling event for each location. Groundwater samples were analyzed for the parameters listed in Table 2.2. Groundwater samples were analyzed by USEPA NRMRL personnel in the field for alkalinity, ferrous iron, free carbon dioxide, pH, reduction/oxidation (redox) potential, soluble manganese, sulfides, and temperature. Analyses for methane, nitrate and nitrite, sulfate, purgeable aromatic hydrocarbons, and total fuel carbon were performed at the NRMRL in Ada, Oklahoma.

2.2.1 Preparation for Sampling

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials were gathered prior to leaving the office. Special care was taken to prevent contamination of the groundwater and extracted samples through cross contamination from improperly cleaned equipment; therefore, water level indicators and sampling equipment were thoroughly cleaned before and after field use and between uses at different sampling locations. In addition, a clean pair of new, disposable gloves was worn each time a different well/point was sampled.

All portions of sampling and test equipment that contacted the sample were thoroughly cleaned before use. This equipment included the water level probe and cable, equipment for measuring onsite groundwater chemical parameters, and other equipment that contacted the samples. All peristaltic pump tubing was dedicated to each sampling location. The following cleaning protocol was used:

TABLE 2.2
ANALYTICAL PROTOCOL
GROUNDWATER AND SOIL SAMPLES
BUILDING 1212
REMEDATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

MATRIX Analyte	METHOD	FIELD (F) OR FIXED-BASE LABORATORY (L)
WATER		
Total Iron	Colorimetric, Hach® Method 8008	F
Ferrous Iron (Fe ²⁺)	Colorimetric, Hach® Method 8146	F
Ferric Iron (Fe ³⁺)	Difference between total and ferrous iron	F
Redox Potential	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	E150.1/SW9040, direct-reading meter	F
Conductivity	E120.1/SW9050, direct-reading meter	F
Temperature	E170.1, direct-reading meter	F
Alkalinity (Carbonate [CO ₃ ²⁻] and Bicarbonate [HCO ₃ ⁻])	F = Titrimetric, Hach® Method 8221 L = USEPA Method 310.1	F L
Nitrate + Nitrite	USEPA Method 353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane	RSKSOP-147	L
Dissolved Organic Carbon	RSKSOP-102	L
Aromatic Hydrocarbons	RSKSOP-148	L
Fuel Carbon	RSKSOP-148	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Aromatic Hydrocarbons	RSKSOP-124, modified	L

- Cleaned with potable water and phosphate-free laboratory detergent;
- Rinsed with potable water;
- Rinsed with distilled or deionized water;
- Air dried prior to use.

Any deviations from these procedures were documented in the field scientist's field notebook and on the groundwater sampling form. Decontaminated fluids were contained as described in Section 2.1.1.2.

As required, field analytical equipment was calibrated according to the manufacturers' specifications prior to field use. Because the majority of physical and chemical analyses were performed by USEPA NRMJL personnel, this requirement applied specifically to onsite chemical measurements of DO and temperature.

Prior to removing any water from the well, the static water level was measured. An electrical water level probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot. After measurement of the static water level, the water level probe was lowered to the bottom of the well for measurement of total well depth (recorded to the nearest 0.01 foot). Based on these measurements, the volume of water to be purged from the wells was calculated.

2.2.2 Well/Point Purging and Sample Collection

A peristaltic pump with dedicated high density polyethylene (HDPE) tubing was used for well evacuation. Purging consisted of removing at least three times the calculated casing volume prior to sample collection. Once three casing volumes were removed from the well, purging continued until the DO, temperature, and conductivity readings had stabilized. Purge waters generated during the site characterization event were placed in 5-gallon buckets and transported to the on-site 1,200-gallon waste water tank.

A peristaltic pump with dedicated HDPE tubing was used to extract groundwater samples from each well or Geoprobe® point. The groundwater sample was transferred directly into the appropriate sample container. The water was carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Sample bottles for BTEX and total fuel carbon analysis were filled so that there was no headspace or air

bubbles within the container. Table 2.2 lists the analyses performed on collected groundwater samples.

2.2.3 Onsite Chemical Parameter Measurement

Measurement of DO, pH, specific conductance, redox potential, and temperature was performed at the sampling location at the time of sample collection. All other field parameters were measured onsite by USEPA NRMRL personnel at their mobile laboratory immediately following sample collection.

DO measurements were taken using a YSI-55 DO meter in a HDPE beaker at the outlet of the peristaltic pump. DO concentrations were recorded after the readings stabilized, and in all cases represent the lowest DO concentration observed.

Because the specific conductance, pH, redox potential, and temperature of groundwater can change significantly within a short time following sample acquisition, conductivity and temperature parameters were measured in the field using an Extech® meter, in the same beaker used for DO measurements. Redox potential and pH were measured by the USEPA NRMRL personnel.

2.2.4 Sample Handling

The USEPA provided appropriate pre-preserved sample containers. Samples were delivered to the USEPA mobile laboratory within minutes of sample collection. Samples for those analyses not performed by the mobile laboratory were appropriately packaged and shipped by the USEPA field personnel to the NRMRL in Ada, Oklahoma for analysis. The associated chain-of-custody documentation for the fixed-base laboratory was the responsibility of the USEPA NRMRL field personnel.

The sample containers were filled as described in Sections 2.2.3, and the container lids were tightly closed. The sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

- Facility name;
- Sample identification;

- Requested Analysis;
- Sample type (groundwater);
- Sampling date;
- Sampling time;
- Preservatives added; and
- Sample collector's initials.

2.3 AQUIFER TESTING

Slug tests were performed in May 1996 in wells MW-3, MW-5, MW-6, MW-7, MW-10, and MW-11 (Figure 2.1) to provide estimates for the hydraulic conductivity of the shallow saturated zone in the vicinity of Building 1212. Slug tests are single-well hydraulic tests used to estimate the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug testing can be performed using either a rising head or a falling head test. Both rising head and falling head tests were used at this site. Detailed slug testing procedures are presented in the *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater* (Wiedemeier *et al.*, 1995), hereafter referred to as the technical protocol document.

Data obtained during slug testing were analyzed using the computer program AQTESOLV® (Geraghty & Miller, Inc., 1994) and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The results of slug testing are presented in Section 3.3 and Appendix A.

2.4 SURVEYING

After completion of field work in May 1996, the locations and elevations of all new monitoring wells were surveyed by Century West Surveying, a licensed land surveying company from Spokane, Washington. The horizontal locations and elevations of the measurement datum (top of PVC well casing) and the ground surface adjacent to the well casing were measured relative to existing control points referenced to the Washington State plane coordinate system. Horizontal locations were surveyed to the nearest 0.1 foot. Measurement datum and ground surface elevations were surveyed to the nearest 0.01 foot and referenced to mean sea level (msl) elevation. Survey data are presented in Table 2.1 and Appendix A. The locations of Geoprobe® grab samples were estimated by measuring the distance between adjacent monitoring wells and surface references.

SECTION 3

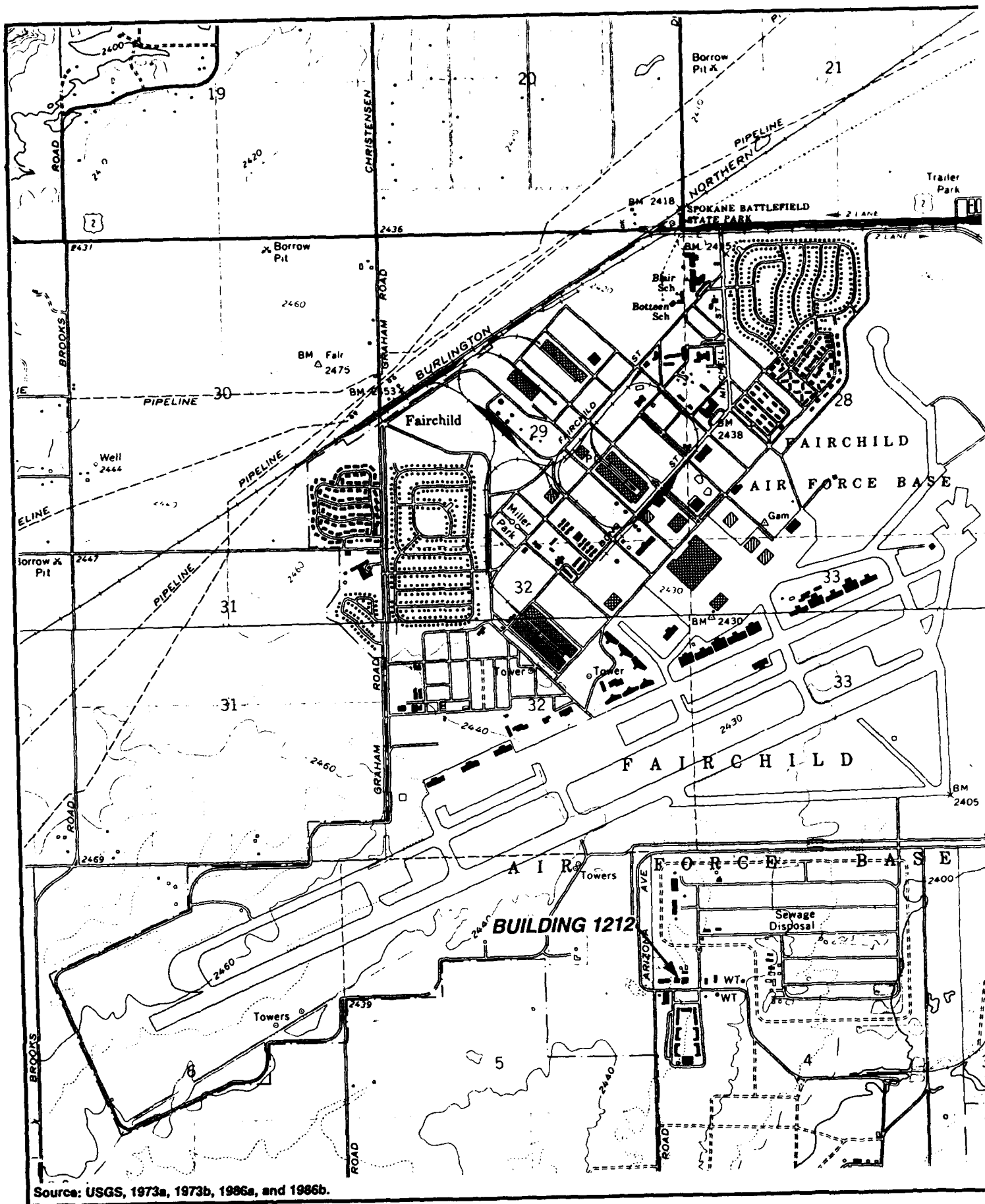
PHYSICAL CHARACTERISTICS OF THE STUDY AREA

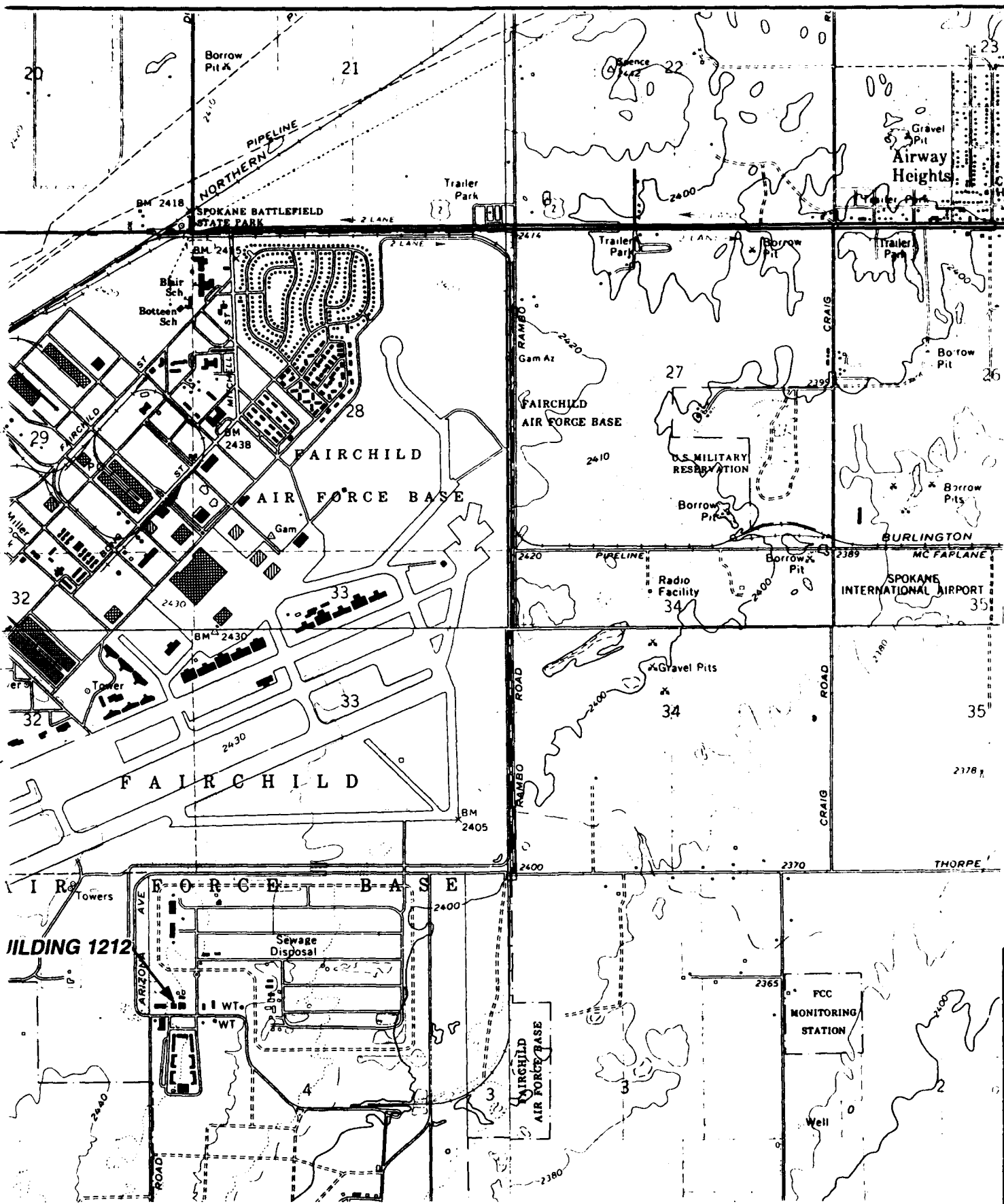
This section describes the physical characteristics of Building 1212 as determined from data collected by Parsons ES in May 1996, in conjunction with data documented in previous reports on Fairchild AFB. Investigative techniques used by Parsons ES to determine the physical characteristics of the site are discussed in Section 2.

3.1 SURFACE FEATURES

3.1.1 Topography

Fairchild AFB is located within the Columbia Basin in the northeastern corner of the 55,000-square-mile Columbia Plateau Physiographic Province (ICF Technology Inc., 1995). The Columbia Plateau is bordered by mountains and highlands on all side. The northern edge of the Plateau gives way to the Okanogan Highlands roughly 75 miles north of Fairchild AFB, while the eastern end of the Plateau is bordered by the Rocky Mountains, approximately 75 miles east of Fairchild AFB. The Plateau extends approximately 250 miles to the south and west of the Base. The Blue Mountains border the Plateau on the south, and the Cascade Mountains border the Plateau on the west. There is a watershed divide in the center of the Plateau that causes streams north of this divide to flow in a northerly direction, and streams south of the divide to flow in a southerly direction. The topography of the region was shaped by glacial flood waters that eroded the surface of the Columbia Plateau during the Pleistocene Epoch (approximately 22,000 years ago) (HNUS, 1993a). The surface topography of the Base and surrounding region is generally flat to gently rolling grasslands sloping slightly to the east-northeast. Ground surface elevations on the Base range from 2,400 to 2,460 feet above mean sea level (ft msl) (Figure 3.1).





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3.1.2 Surface Water Hydrology

Fairchild AFB is located in the northern half of the Columbia Plateau, north of the watershed divide. All surface water drainage in this region of the Columbia Plateau generally flows to the north or northwest (Flint, 1936). The Base is approximately 7 miles west-southwest of the Spokane River, which flows through the city of Spokane [US Geological Survey (USGS), 1973a, 1973b, 1986a, and 1986b]. Two other drainages in the vicinity of the Base are Deep Creek and Marshall Creek, located approximately 2 miles northwest and 8 miles southeast of the Base, respectively. These creeks flow northwest and join the Spokane River, which drains this region of the Plateau. Surface water on the Base is generally limited to precipitation runoff and intermittent flow in no name ditch near the eastern boundary of the Base. Precipitation runoff is controlled within a series of manmade ditches. Reportedly, water collected in the ditch system does not leave Base property, and surface water either infiltrates the subsurface or evaporates (HNUS, 1993a). At Building 1212, storm precipitation enters the storm drain system or infiltrates into the ground.

3.1.3 Manmade Features

Building 1212 is located within the US Air Force Survival Training school complex. The building is used for vehicle maintenance and as the Transportation Resistance Training Facility. North of the building is a fenced storage yard for vehicles and seasonal equipment. An oil/water separator is located in the storage yard on the northeast corner of Building 1212. A 4,000 gallon-UST and gasoline pump island are located south of the Building (Figure 1.3). The remainder of the site is covered by a broad expanse of asphalt and concrete, with the exception of a grassy area between the Building 1212 lot and Artillery Road. West and east of Building 1212 are Buildings 1207 and 1228, respectively (Figure 1.3). South to southeast of the site is approximately 1.5 acres of landscaped grass.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

The shallow subsurface geology at Fairchild AFB is a mixture of Quaternary sediments consisting of eolian, glacial, fluvial, and lacustrine deposits. Flood waters from the glacial-era Missoula Lake scoured the basalt bedrock of this region of the Columbia Plateau. Coarse sediments were deposited during the early recession of flood waters, followed by finer sediments during the later stages of floodwater recession. The

alluvium in the vicinity of the Base generally consists of fine-grained sediments deposited by receding glacial flood waters. Clays and silts are intermixed with sandy silts, clays, and gravels (HNUS, 1993a). In addition, loess (windblown silt) deposits are interbedded in portions of the unconsolidated deposits. Unconsolidated deposits generally follow the slope of the underlying basalt bedrock (ICF Technology, Inc., 1995).

Bedrock in the vicinity of the Base is mostly Tertiary basalts of the Columbia River Group. Basalts below Fairchild AFB are of the Wanampum Formation (HNUS, 1993a). The basalt flows in the region are interbedded with sedimentary clay and silt units of the Latah Formation. These layers were deposited when stream beds were isolated by the volcanic basalt flows (Cline, 1969). The Wanampum Basalt flow below the Base appears to be divided into an upper and lower flow sequence by an interbed of the Latah Formation. The upper basalt flow is 166 feet to 193 feet thick across the Base. The surface of the upper basalt flow is vesiculated, deeply fractured, and highly weathered in places. Just east of the Base the upper basalt layer was completely eroded away by the Missoula Lake flood waters. The middle of this flow contains few vesicles and fractures; the formation becomes more massive and competent with depth. The underlying Latah Formation deposits consist of an extensive silty claystone that ranges in thickness from 8.5 to 10 feet (HNUS, 1993a). Information on the geologic characteristics of the lower basalt flow was not available in the previous reports reviewed as part of this investigation. However, this unit is isolated from the overlying units; therefore, its geologic characteristics are not pertinent to the Building 1212 site characterization.

Groundwater in the vicinity of the Base is encountered from 8 to 12 feet bgs and is found in both the unconsolidated material and the underlying basalt bedrock. Recharge of the surficial aquifer under the Base is expected to come from upgradient flow and surface runoff infiltration. Groundwater flow in the unconsolidated deposits is through intergranular pore space, while flow in the basalt is through interconnecting fractures (HNUS, 1993a). Flow across the Base is generally to the east and east-northeast, but local variations may result from local changes in bedrock topography. Groundwater in the unconsolidated material and shallow bedrock is generally unconfined, with some local semiconfined areas. The unconsolidated material and the shallow basalt are hydraulically connected by fractures, vesicles, and weathered zones. The middle region of the shallow basalt flow is more competent with less fracturing, and acts as an aquitard. The

interbedded claystone between the basalt flows also acts as a confining layer (HNUS, 1993a).

3.3 SITE GEOLOGY AND HYDROGEOLOGY

Characterization of the Quaternary sediments at Building 1212 was accomplished during this RNA investigation. There are currently 13 groundwater monitoring wells installed at Building 1212, including 1 well screened at the base of the unconsolidated aquifer zone.

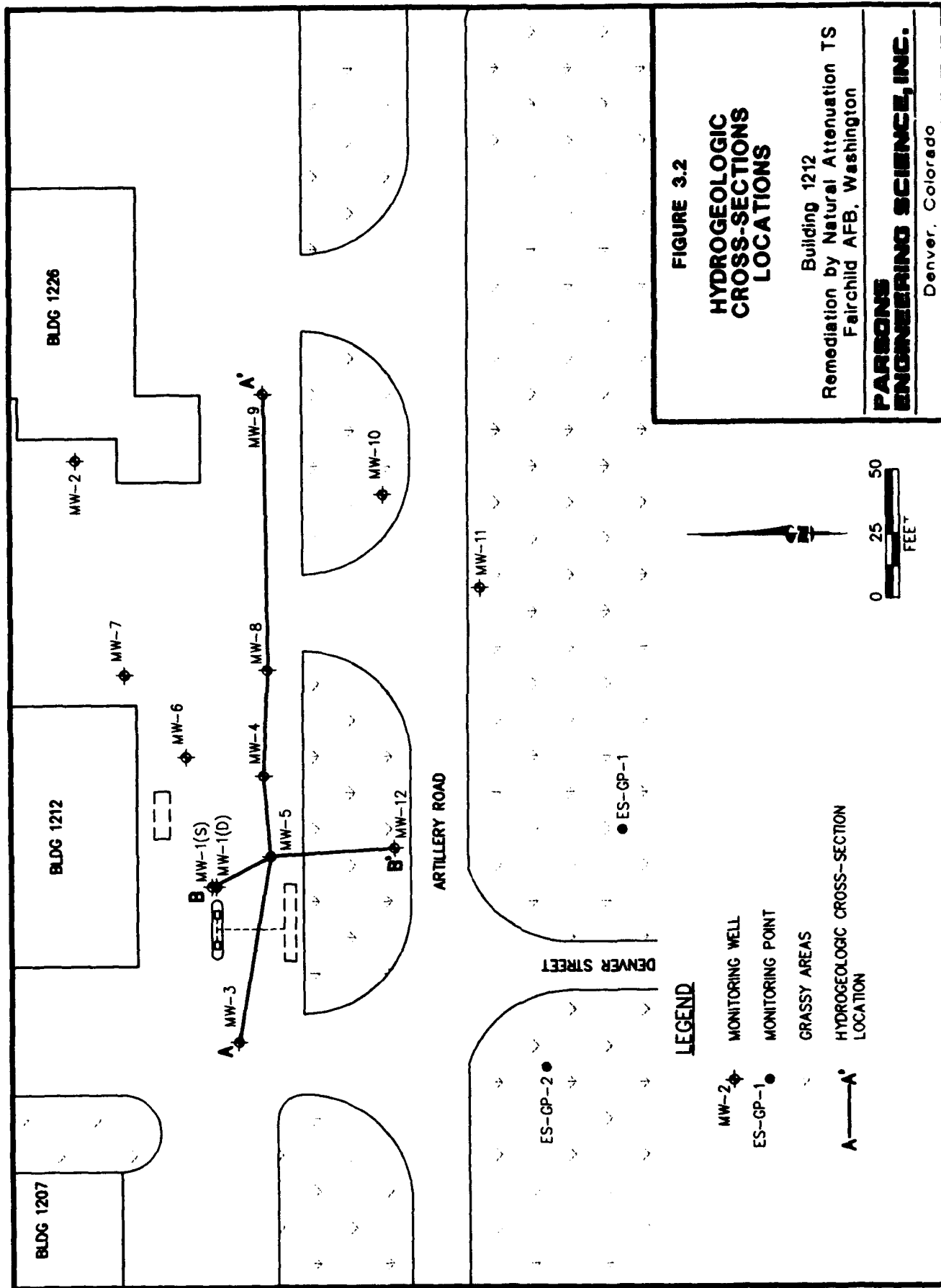
3.3.1 Lithology and Stratigraphic Relationships

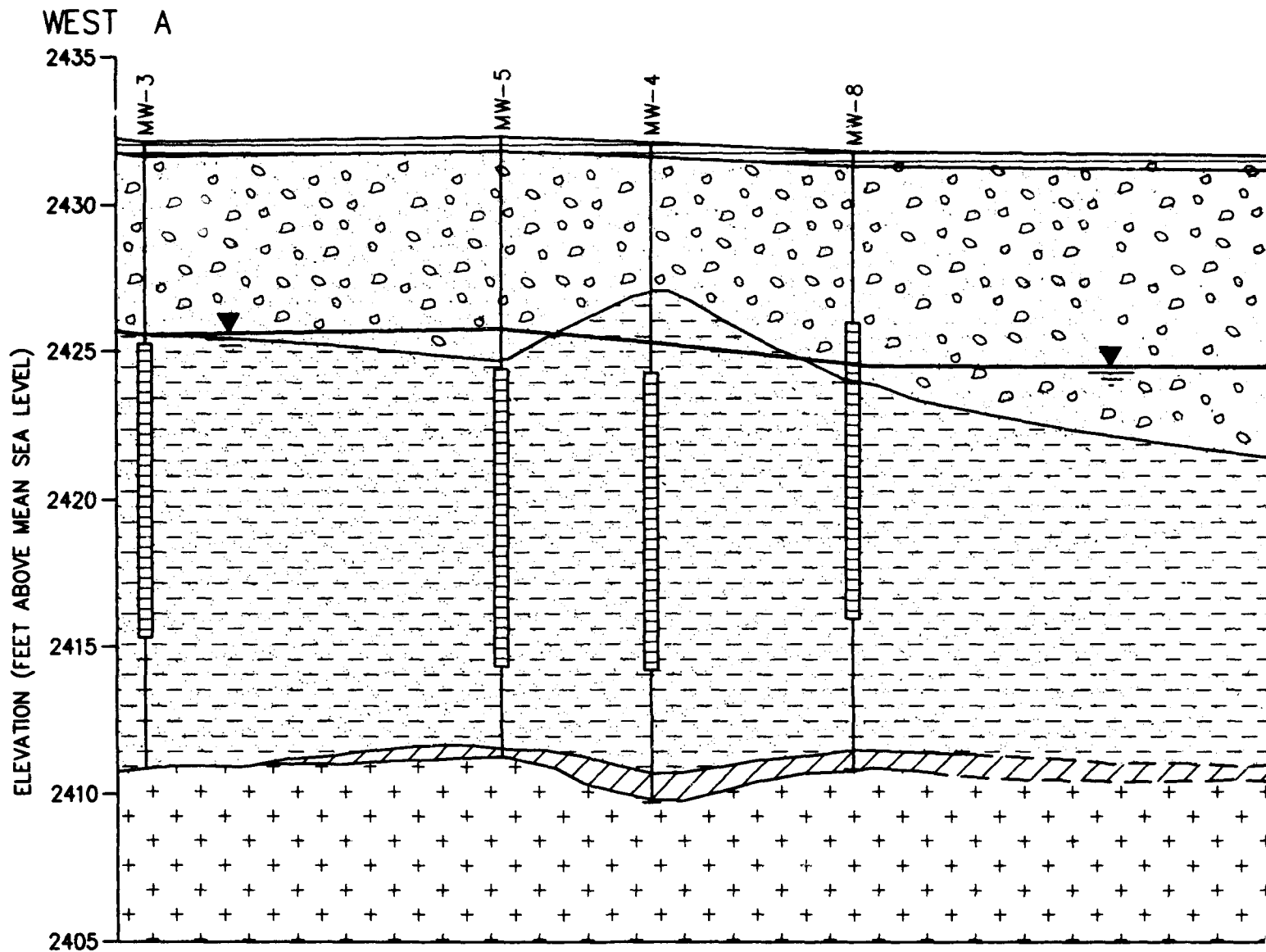
Surface soils at the site primarily consist of Cheney and Uhlig Series clayey silts, and the description of subsurface soils underlying Building 1212 is relatively consistent with the regional geology described in Section 3.2. Unconsolidated material overlying the basalt bedrock ranges in thickness from 20 feet to 25.5 feet across the site. Shallow deposits at Building 1212 are primarily clayey silts and coarse sands, while deeper unconsolidated material appears to be clayey silts overlying weathered basalt fragments. The upper 6 to 7 feet of material at Building 1212 consists of a gravelly, medium to coarse sand. This unit is underlain by 10 to 20 feet of moist, tan-brown silt with clay. Below the silt is 0.5 to 1 foot of intermixed clay and weathered basalt fragments overlying the basalt bedrock.

To illustrate these stratigraphic relationships, hydrogeologic sections have been developed from subsurface data derived from logs of the newly installed monitoring wells. Hydrogeologic cross sections A-A' and B-B' depict the unconsolidated material and the top of the shallow region of the upper basalt bedrock underlying the site. Figure 3.2 shows the locations of these sections. Figure 3.3 presents hydrogeologic section A-A', which is approximately parallel to the direction of groundwater flow and hydrogeologic section B-B', which is approximately perpendicular to the direction of groundwater flow.

3.3.2 Groundwater Hydraulics

Groundwater at the site resides in the Quaternary glacial deposits and in the underlying upper basalt bedrock. Depth to groundwater is approximately 5 to 7 feet bgs across the majority of the site. A summary of groundwater measurements from May and July 1996





LEGEND

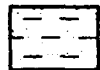
PROFILE A-A'



ASPHALT



GRAVELLY SAND



CLAYEY SILT



WEATHERED BASALT AND CLAY



BASALT BEDROCK



MONITORING
WELL ID

WELL SCREEN
(DASHED LINE = APPROX ELEVATION)

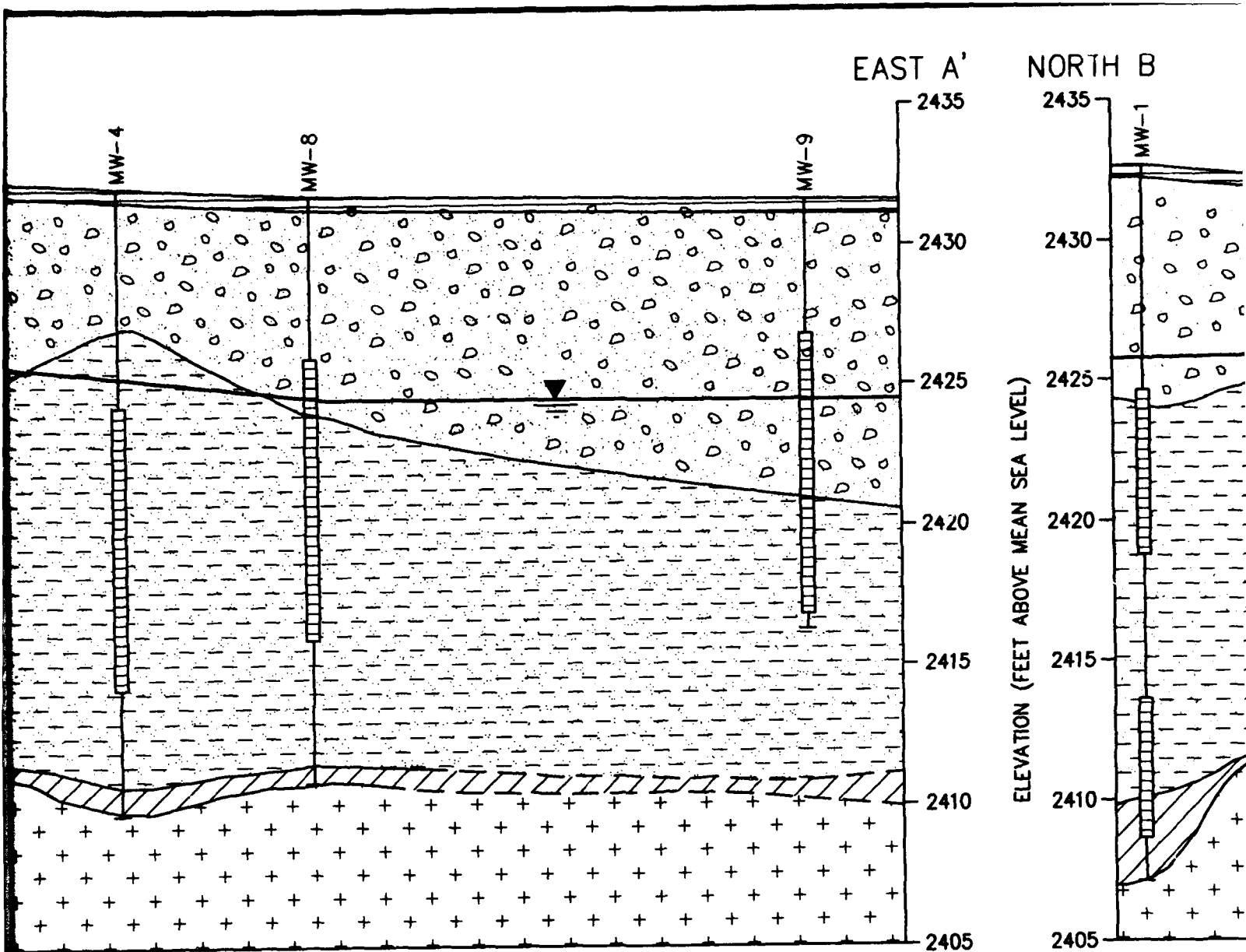
TOTAL DEPTH OF BOREHOLE

GEOLOGIC CONTACT

DASHED WHERE INFERRED



WATER TABLE - 7/96



PROFILE A-A'

- MW-5
- MONITORING WELL ID
- WELL SCREEN (DASHED LINE = APPROX ELEVATION)
- TOTAL DEPTH OF BOREHOLE
- GEOLOGIC CONTACT
- DASHED WHERE INFERRED
- WATER TABLE - 7/96

is presented in Table 3.1. Construction details for monitoring wells are presented in Table 2.1.

3.3.2.1 Flow Direction and Gradient

In the immediate vicinity of the site, groundwater flows to the east and southeast, which is roughly consistent with the regional flow direction. Figure 3.4 shows the groundwater surface at Building 1212 in July 1996. The hydraulic gradient at the site decreases from approximately 0.017 foot per foot (ft/ft) south of the former gasoline USTs to approximately 0.009 ft/ft east of the site near Building 1226. Typically, groundwater elevations at Fairchild AFB are lower during August through November, and higher during April through July (ICF Technology, Inc., 1995).

The monitoring well pair MW-1(S) and MW-1(D) was used to evaluate vertical hydraulic gradients and the vertical extent of contamination in groundwater underlying Building 1212. Groundwater elevation data collected in July 1996 suggest a downward vertical gradient of 0.086 ft/ft. These observations suggest that, in general, groundwater is migrating from the unconsolidated deposits toward the shallow bedrock. However, the dominant transport direction of dissolved contaminants in groundwater is to the east and southeast.

3.3.2.2 Hydraulic Conductivity

In May 1996, Parsons ES estimated the hydraulic conductivity at wells MW-3, MW-5, MW-6, MW-7, MW-10, and MW-11 using falling/rising head slug tests and the method of Bouwer and Rice (1976) as described in Section 2. The results of these slug tests are summarized in Table 3.2. Hydraulic conductivities ranging from 0.42 to 2.35 feet per day (ft/day) were estimated for five wells screened near the top of the water table at Building 1212. Monitoring well MW-11, which was screened in a thicker gravel unit, had an estimated average hydraulic conductivity of 21.43 ft/day. The average hydraulic conductivity of the wells in the clay unit as determined from these tests is approximately 1.0 ft/day.

TABLE 3.1
SUMMARY OF GROUNDWATER ELEVATION DATA
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Well	Measurement	Elevation	Depth to	Groundwater
Indentification	Date	Top of Casing (feet msl) ^{a/}	Groudwater (feet btoc) ^{b/}	Elevation (feet msl)
MW-1(S)	7/17/96	2432.50	6.59	2425.91
	5/28/96	2432.50	6.69	2425.81
MW-1(D)	7/17/96	2432.45	7.53	2424.92
	5/28/96	2431.45	7.76	2423.69
MW-2	7/17/96	2432.50	8.88	2423.62
	5/28/96	2432.50	8.41	2424.09
MW-3	7/17/96	2432.03	6.47	2425.56
	5/28/96	2432.03	6.48	2425.55
MW-4	7/17/96	2431.86	6.46	2425.40
	5/28/96	2431.86	8.82	2423.04
MW-5	7/17/96	2432.12	6.18	2425.94
	5/28/96	2432.12	6.64	2425.48
MW-6	7/17/96	2432.53	7.55	2424.98
	5/28/96	2432.53	7.34	2425.19
MW-7	7/17/96	2432.30	7.42	2424.88
	5/28/96	2432.30	7.15	2425.15
MW-8	7/17/96	2431.70	7.02	2424.68
	5/28/96	2431.70	12.36	2419.34
MW-9	7/17/96	2431.74	7.3	2424.44
	5/28/96	2431.74	6.98	2424.76
MW-10	7/17/96	2430.86	6.41	2424.45
	5/28/96	2430.86	6.13	2424.73
MW-11	7/17/96	2430.36	6.9	2423.46
	5/28/96	2430.36	5.62	2424.74
MW-12	7/17/96	2430.79	5.63	2425.16
	5/28/96	2430.79	10.37	2420.42

^{a/} feet msl = Feet above mean sea level.

^{b/} feet btoc = Feet below top of casing.

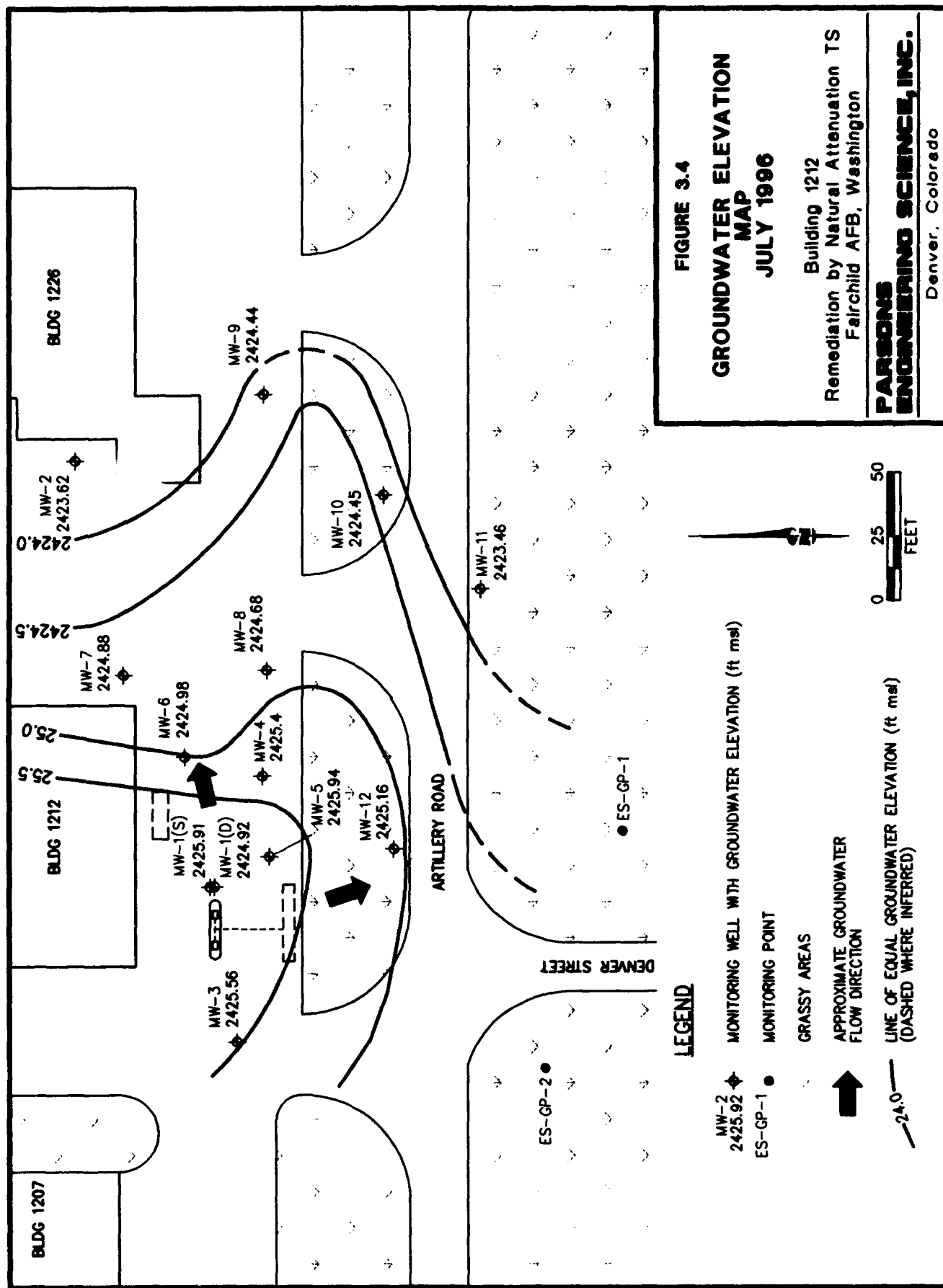


TABLE 3.2
MAY 1996 SLUG TEST RESULTS
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

WELL	HYDRAULIC CONDUCTIVITY (ft/day)	HYDRAULIC CONDUCTIVITY (ft/min)
MW-3	2.35	0.0016
MW-5	0.45	0.00031
MW-6	0.73	0.00051
MW-7	1.05	0.00073
MW-10	0.42	0.00029
MW-11	21.43	0.019

3.3.2.3 Effective Porosity

Because of the difficulty involved in accurately determining effective porosity, accepted literature values for the type of soil making up the shallow saturated zone were used. Walton (1988) gives ranges of effective porosity for silt of 0.01 to 0.30. An average effective porosity of 0.15 was assumed for this project.

3.3.2.4 Advective Groundwater Velocity

The advective velocity of groundwater in the direction parallel to groundwater flow is given by:

$$\bar{v} = \frac{K}{n_e} \frac{dH}{dL}$$

Where: \bar{v} = Average advective groundwater velocity (seepage velocity) [L/T]

K = Hydraulic conductivity [L/T] (1.0 ft/day)

dH/dL = Gradient [L/L] (0.017 ft/ft)

n_e = Effective porosity (0.15).

Using this relationship in conjunction with site-specific data, the average advective groundwater velocity at the site in May 1996 was 0.11 ft/day, or approximately 40 feet per year.

3.3.2.5 Preferential Flow Paths

Preferential contaminant migration pathways were identified during the field work phase of this project. Man-made features such as utility trenches or storm sewers are present at the site; furthermore, the relatively low hydraulic conductivity of the surficial aquifer materials could increase the influence of the man-made pathways. In May 1996, the water level was at least 6 feet bgs (Table 3.1) and was not known to intercept the utility trenches that parallel Artillery Road. It is possible that a utility corridor passing near the gasoline UST area could serve as a preferential conduit for contaminated groundwater during periods of elevated groundwater level.

3.3.3 Groundwater Use

Groundwater in the shallow aquifer in the vicinity of the Base is not known to be used as a drinking water supply. Neighborhoods to the east and northeast of the Base obtain domestic and agricultural water primarily from private wells that tap aquifers in the deeper basalt flows. The closest residential neighborhoods are roughly 1,800 feet east (downgradient) of the site. Base drinking water is primarily supplied from a Base-owned well field 10 miles northwest of the Base. Additionally, there is a water supply well located in the southern area of the Base. This well also produces water from the basalt aquifer and supplies roughly 10 percent of the Base's needs (HNUS, 1993a).

3.4 CLIMATE

Fairchild AFB is surrounded by semi-arid grasslands common to this area of the Columbia Basin. The Base receives approximately 16 inches of rainfall during the warm dry summers, and 40 inches of snowfall during the cool, damp winter months. The prevailing wind direction in the region is to the northeast at an average speed of 8 miles per hour (ICF Technology, Inc., 1995). The average evapotranspiration rate for the region is reported at 12.8 inches per year (JRB Associates, 1985). Maximum infiltration rates usually occur during the early spring when snow melt runoff combines with precipitation while temperatures are still cool and evapotranspiration is low (HNUS, 1993a).

SECTION 4

NATURE AND EXTENT OF CONTAMINATION AND SOIL AND GROUNDWATER GEOCHEMISTRY

4.1 SOURCE OF CONTAMINATION

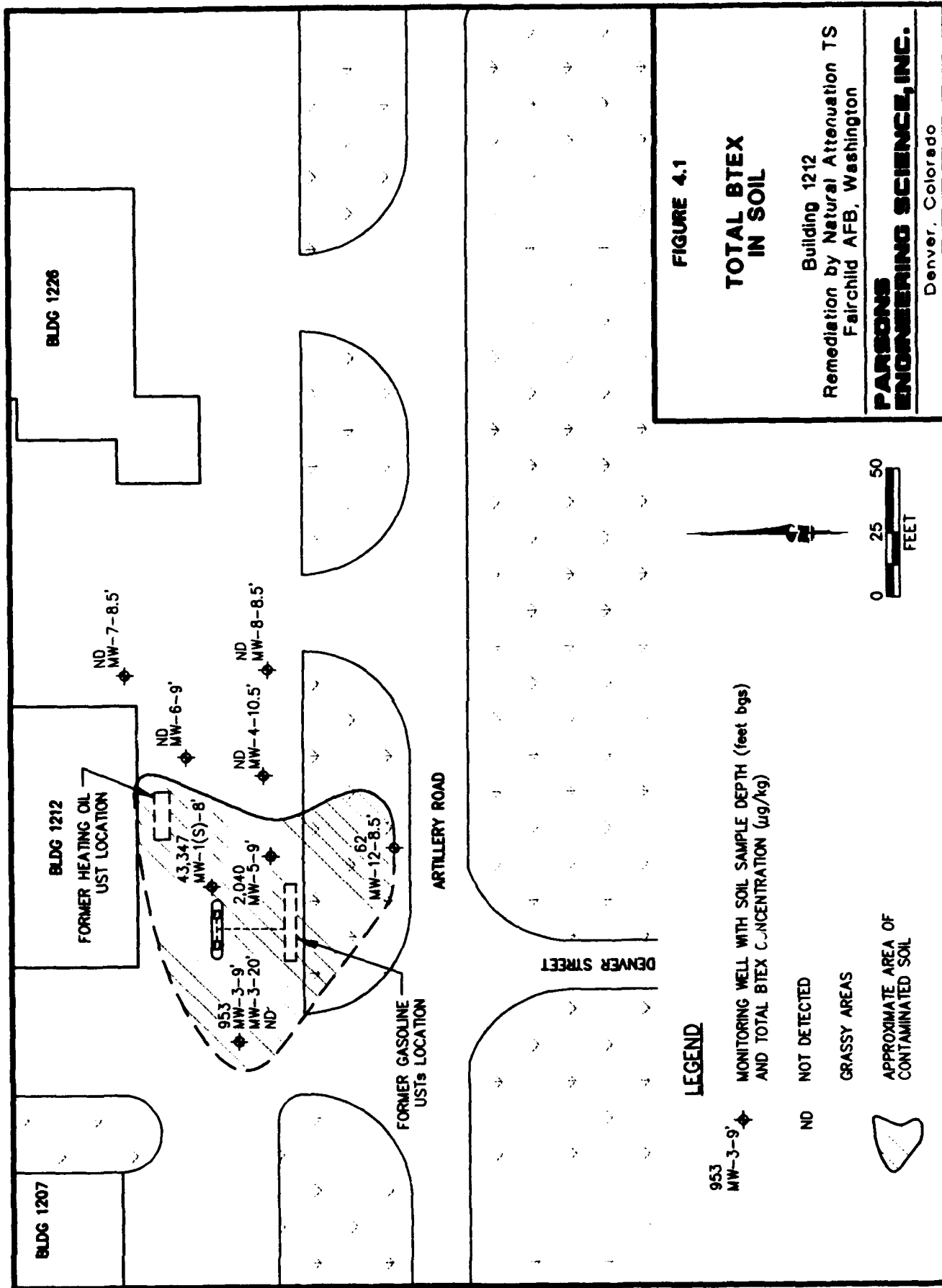
The periodic releases of gasoline and heating oil from the former USTs and associated piping have been identified as the source of contamination at Building 1212. However, neither the frequency of leakage nor the volume of fuels released into the soil is known. Currently at Building 1212, no visibly contaminated surface soils or stressed vegetation is present.

4.2 SOIL CHEMISTRY

During the May 1996 investigation, nine soil samples were collected at eight locations at Building 1212 and analyzed for BTEX. These soil sampling locations were identified as MW-1, MW-3 through MW-8, and MW-12 (Figure 4.1). Eight samples were collected at depths of 8.5 to 10.5 feet; the ninth sample was collected at 20.5 feet bgs, within 2 feet of bedrock. Previously, site soils were characterized only at the time of UST remediation (Budinger and Associates 1995), when soil samples were collected from the gasoline tanks excavation and the stockpile of soils from the heating oil tank removal. The 1995 samples were analyzed for BTEX and total petroleum hydrocarbons (TPH). Results of the Budinger and Associates soil investigation are presented in Appendix A.

4.2.1 Soil BTEX

Detectable concentrations of BTEX compounds were present in four of the nine samples collected for analysis in May 1996. Four of the five soil samples that did not exhibit BTEX contamination were collected downgradient from the source area. The remaining soil sample that did not exhibit BTEX contamination was the sample collected from 20.5 feet bgs at borehole MW-3. The presence of contamination in the 9-foot sample at MW-3 together with the absence of contamination in the 20.5-foot sample suggests that the vertical extent of soil contamination is less than 20 feet bgs. The lateral



area of residual soil LNAPL contamination is approximately 9,000 square feet. Table 4.1 presents the BTEX results from the May 1996 soil analyses.

The highest total BTEX concentration of 43,347 micrograms per kilogram ($\mu\text{g/kg}$) was detected in a soil sample from near the groundwater surface (8 feet bgs) at borehole MW-1 (Figure 4.1). MW-1 is located adjacent to the gasoline dispensers approximately 30 feet south of Building 1212. The next highest BTEX concentration (2,040 $\mu\text{g/kg}$) was detected in a soil sample from borehole MW-5 (downgradient from the former gasoline USTs) at 9 feet bgs. A total BTEX concentration of 953 $\mu\text{g/kg}$ was detected approximately 30 feet west of the dispensers and former USTs in a soil sample from 9 feet bgs at borehole MW-3. A benzene concentration of 62 $\mu\text{g/kg}$ was the only BTEX compound detected in a soil sample from 8.5 feet bgs at borehole MW-12. In boreholes MW-3 and MW-12, the headspace readings of soil samples collected above the analytical samples were similar to background values, suggesting that soil contamination in the vicinity of boreholes MW-3 and MW-12 is due to the smearing of groundwater contaminants onto the subsurface soil.

4.2.2 Total Organic Carbon

TOC concentrations are used to estimate the amount of organic matter sorbed to soil particles or trapped in the interstitial passages of a soil matrix. In the saturated zone, sorption results in retardation of the contaminant plume relative to the average advective groundwater velocity. TOC results for the nine site soil samples collected in May 1996 range from 0.035 to 0.063 percent. Therefore, an assumed TOC concentration of 0.05 percent was used for estimation of contaminant velocity. Soil TOC results are presented in Table 4.2.

4.3 GROUNDWATER CHEMISTRY

Three lines of evidence can be used to document the occurrence of natural attenuation: 1) geochemical evidence; 2) documented loss of contaminant mass at the field scale; and 3) microcosm studies. The first line of evidence (geochemical evidence) is used herein to support the occurrence of natural attenuation at Building 1212, as described in the following sections. Because this line of evidence strongly suggests that natural attenuation is occurring at this site, and contaminant loss can be documented using a LTM plan, a microcosm study was not deemed necessary.

TABLE 4.1
SOIL HYDROCARBON ANALYTICAL DATA
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Sample		Depth (ft)	Benzene	Toluene	Ethylbenzene	p-Xylene	m-Xylene	o-Xylene	Total	
ID			µg/kg ^{a/}	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	BTEX	µg/kg
MW-1		8	BLQ ^{a/}	447.0	6,550.0	8,650.0	17,100.0	10,600.0	43,347.0	
MW-3		9	47.2	157.0	175.0	187.0	195.0	192.0	953.2	
MW-3		20.5	ND ^{a/}	BLQ	ND	ND	ND	ND	ND	
MW-4		10.5	ND	BLQ	ND	ND	ND	ND	ND	
MW-5		9	ND	38.5	457.0	647.0	617.0	280.0	2,039.5	
MW-6		9	ND	BLQ	ND	BLQ	BLQ	ND	ND	
MW-7		8.5	ND	BLQ	ND	ND	ND	ND	ND	
MW-8		8.5	ND	BLQ	ND	ND	ND	ND	ND	
MW-12		8.5	61.5	BLQ	ND	BLQ	BLQ	ND	61.5	

^{a/} µg/kg = Micrograms per kilogram.

^{b/} BLQ = Analyte detected below limit of quantitation, 0.05 µg/kg.

^{c/} ND = Not detected.

TABLE 4.2
SOIL TOTAL ORGANIC CARBON DATA
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Sample ID	Sample Depth (feet)	Filtrate % OC ^a	Solids % OC	Total % TOC	Mean % TOC ^b
MW-1	8	0.007	0.032	0.039	
MW-1d ^c	8	0.016	0.034	0.050	0.045
MW-3	9	0.007	0.054	0.061	
MW-3d	9	0.007	0.056	0.063	0.062
MW-4	10.5	0.006	0.029	0.035	
MW-4d	10.5	0.007	0.033	0.040	0.038
MW-5	9	0.004	0.054	0.058	
MW-5d	9	0.013	0.054	0.067	0.063
MW-6	9	0.012	0.051	0.063	
MW-6d	9	0.010	0.049	0.059	0.061
MW-7	8.5	0.009	0.034	0.043	
MW-7d	8.5	0.004	0.039	0.043	0.043
MW-12	8.5	0.004	0.028	0.032	
MW-12d	8.5	0.007	0.030	0.037	0.035

^a OC = Organic carbon.

^b TOC = Total organic carbon.

^c d = Duplicate.

4.3.1 Dissolved Hydrocarbon Contamination

Groundwater samples had not been collected at Building 1212 prior to the May 1996 sampling event conducted by Parsons ES. In the May 1996 sampling event, groundwater samples were collected from 13 newly installed monitoring wells and 2 temporary Geoprobe® push locations. All samples were analyzed for BTEX and fuel carbon (Table 2.2). Table 4.3 summarizes groundwater analytical results from the May 1996 sampling event.

The areal distribution of total dissolved BTEX in groundwater for May 1996 is presented on Figure 4.2. At MW-1S and MW-1D, isopleths are drawn on the basis of the shallow well concentration. The areal extent of the dissolved BTEX plume defined by the 10-microgram-per-liter ($\mu\text{g/L}$) contour is approximately 22,000 square feet (0.5 acre). The dissolved BTEX contours suggest that gasoline dispensers are the primary source of dissolved BTEX contamination; however, it is possible that releases from the former gasoline USTs and the heating oil UST also may contribute to the dissolved plume. Because of the groundwater flow direction and low permeability aquifer materials in the vicinity of wells MW-4 and MW-8 (Figure 3.4), the dissolved BTEX plume is migrating from the source area along two separate migration pathways. Dissolved contamination from the fuel dispensers is migrating northeast towards the southwest corner of Building 1226, while contamination from the former gasoline USTs is moving southeast towards Artillery Road.

The vertical distribution of dissolved BTEX along the main axis of the plume, approximately parallel to the direction of groundwater flow, is presently unknown. Within the source area, a total BTEX concentration of 6,289 $\mu\text{g/L}$ was detected in a groundwater sample from MW-1(D), which is screened at approximately 19 to 24 feet bgs. MW-1(D) is the only well screened below 20 feet; therefore, no inferences could be made about the vertical distribution of BTEX contamination. However, monitoring well MW-1(D) was installed at the 19 to 24 feet bgs interval based on elevated soil headspace readings at these depths during borehole drilling and soil samples. No other boreholes at the site exhibited elevated soil headspace readings below 20 feet bgs during drilling.

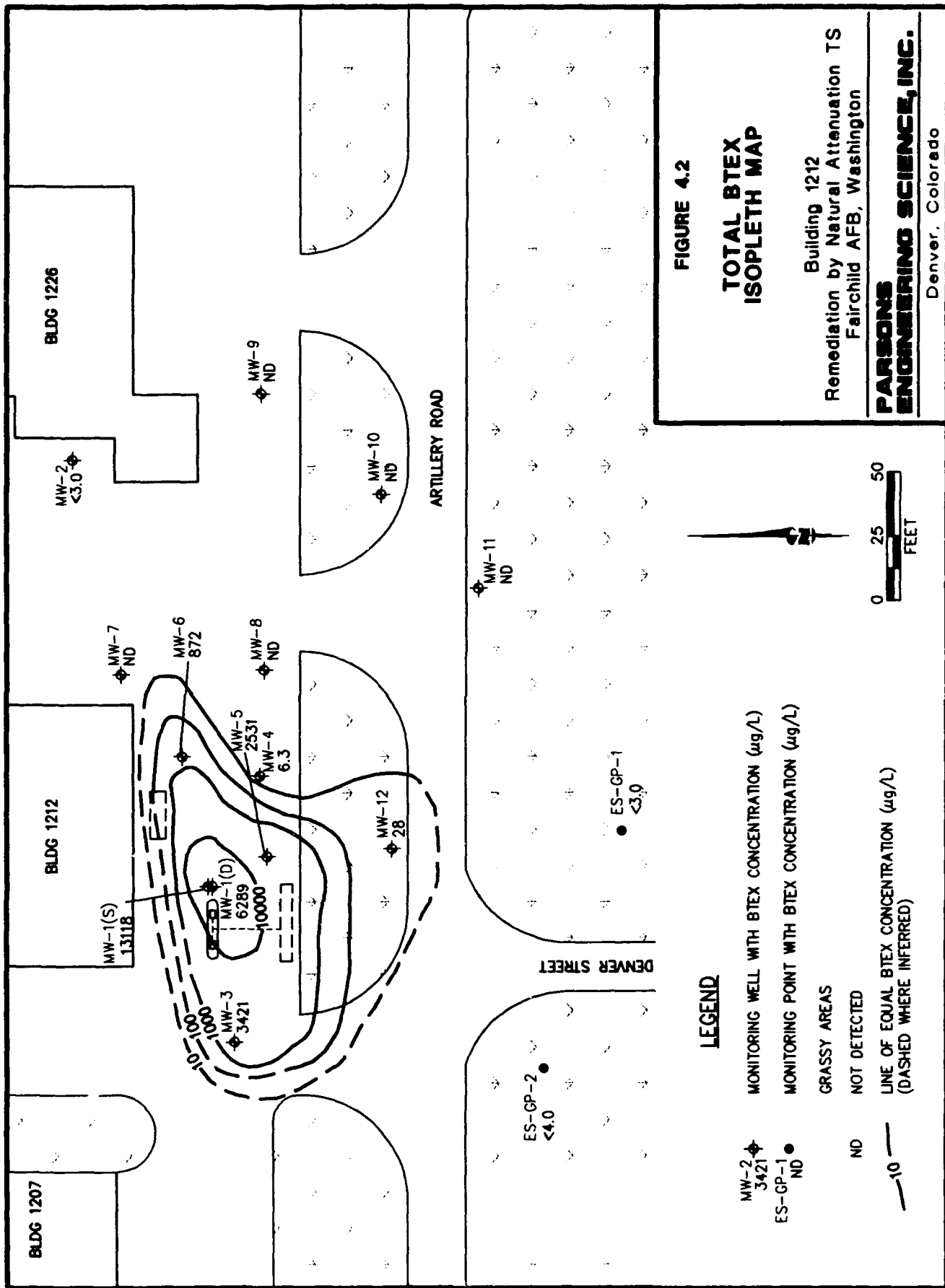
Total BTEX concentrations in groundwater ranged from not detected (ND) at wells MW-7 through MW-11 to 13,118 $\mu\text{g/L}$ at MW-1(S). Well MW-1 is adjacent to the pump island south of Building 1212. Dissolved fuel carbon (normalized to a gasoline standard)

TABLE 4.3
GROUNDWATER HYDROCARBON ANALYTICAL DATA
BUILDING 1212
REMEDICATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Sample ID	Date Sampled	Benzene $\mu\text{g/L}^a$	Toluene $\mu\text{g/L}$	Ethylbenzene $\mu\text{g/L}$	p-Xylene $\mu\text{g/L}$	m-Xylene $\mu\text{g/L}$	o-Xylene $\mu\text{g/L}$	Total	
								BTEX $\mu\text{g/L}$	Fuel Carbon $\mu\text{g/L}$
ES-GP1	5/30/96	<1.0	<1.0	ND ^b	ND	<1.0	ND	<3.0	<1.0
ES-GP2	5/30/96	<1.0	<1.0	ND	ND	<1.0	<1.0	<4.0	<1.0
MW-1(S)	5/29/96	291	673	892	2437	4909	3916	13118	16300
MW-1(D)	5/30/96	109	371	415	1236	2529	1629	6289	10500
MW-2	5/30/96	ND	ND	ND	<1.0	<1.0	<1.0	<3.0	<1.0
MW-3	5/29/96	190	447	558	750	679	797	3421	7097
MW-4	5/29/96	<1.0	<1.0	1.1	1.4	2.4	1.4	6.3	61.0
MW-5	5/29/96	6.8	141	523	726	706	428	2530.8	9530
MW-6	5/29/96	149	15.7	157	194	91.7	265	872.4	2130
MW-7	5/29/96	ND	ND	ND	ND	ND	ND	ND	ND
MW-8	5/29/96	ND	ND	ND	ND	ND	ND	ND	ND
MW-9	5/29/96	ND	ND	ND	ND	ND	ND	ND	ND
MW-10	5/29/96	ND	ND	ND	ND	ND	ND	ND	ND
MW-11	5/29/96	ND	ND	ND	ND	ND	ND	ND	ND
MW-12	5/29/96	25.3	<1.0	<1.0	<1.0	ND	2.3	27.6	93.2

^a $\mu\text{g/L}$ = Micrograms per liter.

^b ND = Not detected.



was analyzed for all May 1996 groundwater samples. The results of the fuel carbon measurements are shown on Figure 4.3 and are listed in Table 4.3. Concentrations of BTEX were detected in all groundwater samples where fuel carbon was detected. Total detected fuel carbon concentrations ranged from <1.0 to 16,300 $\mu\text{g/L}$ (Table 4.3).

4.3.2 Inorganic Chemistry and Geochemical Indicators of BTEX Biodegradation

Microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous redox reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at the site are natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and include oxygen, nitrate, ferric iron, sulfate, manganese, and carbon dioxide.

The driving force of BTEX degradation is electron transfer, which is quantified by the Gibbs free energy of the reaction (ΔG°_r) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of ΔG°_r represents the quantity of free energy consumed or yielded to the system during the reaction. Table 4.4 lists stoichiometry of the redox equations involving BTEX and the resulting ΔG°_r . Although thermodynamically favorable, most of the reactions involved in BTEX oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy (i.e., $\Delta G^\circ_r < 0$). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, manganese, ferric iron hydroxide, sulfate, and finally carbon dioxide.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, manganese reduction, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese or nitrate reduction may dominate if the physical and chemical conditions in

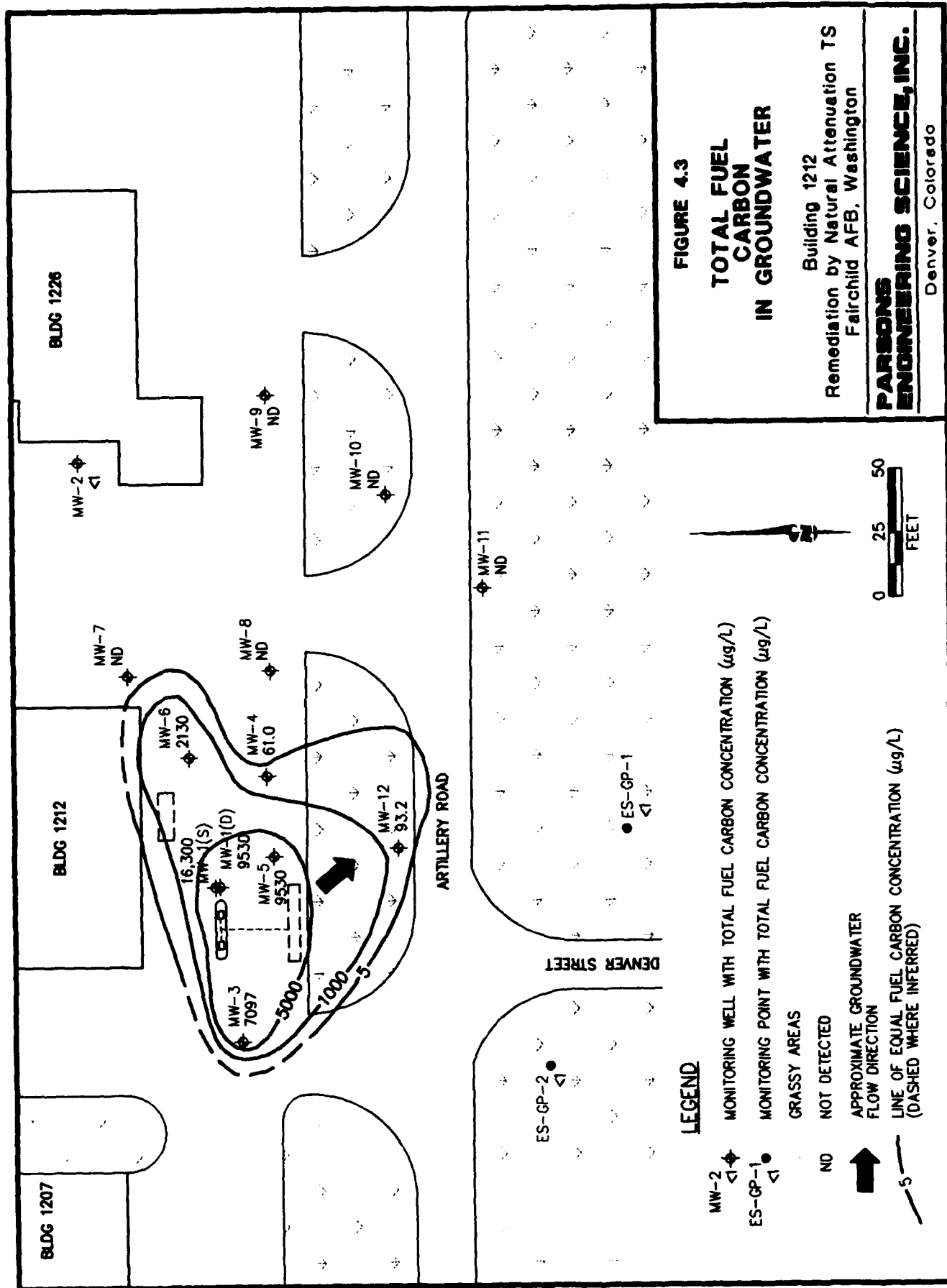


TABLE 4.4
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
 BUILDING 1212
 REMEDIATION BY NATURAL ATTENUATION TS
 FAIRCHILD AFB, WASHINGTON

Coupled Benzene Oxidation Reactions	ΔG°_r (kcal/mole Benzene)	ΔG°_r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5 O_2 + C_6H_6 \Rightarrow 6 CO_{2,g} + 3 H_2O$ <i>Benzene oxidation / aerobic respiration</i>	-765.34	-3202	3.07:1
$6 NO_3^- + 6 H^+ + C_6H_6 \Rightarrow 6 CO_{2,g} + 6 H_2O + 3 N_{2,g}$ <i>Benzene oxidation / denitrification</i>	-775.75	-3245	4.77:1
$60 H^+ + 30 Fe(OH)_{3,s} + C_6H_6 \Rightarrow 6 CO_2 + 30 Fe^{2+} + 78 H_2O$ <i>Benzene oxidation / iron reduction</i>	-560.10	-2343	21.5:1 ^W
$7.5 H^+ + 3.75 SO_4^{2-} + C_6H_6 \Rightarrow 6 CO_{2,g} + 3.75 H_2S^0 + 3 H_2O$ <i>Benzene oxidation / sulfate reduction</i>	-122.93	-514.3	4.61:1
$4.5 H_2O + C_6H_6 \Rightarrow 2.25 CO_{2,g} + 3.75 CH_4$ <i>Benzene oxidation / methanogenesis</i>	-32.40	-135.6	0.77:1 ^W

Coupled Toluene Oxidation Reactions	ΔG°_r (kcal/mole Toluene)	ΔG°_r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9 O_2 + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4 H_2O$ <i>Toluene oxidation / aerobic respiration</i>	-913.76	-3823	3.13:1
$7.2 NO_3^- + 7.2 H^+ + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 7.6 H_2O + 3.6 N_{2,g}$ <i>Toluene oxidation / denitrification</i>	-926.31	-3875	4.85:1
$72 H^+ + 36 Fe(OH)_{3,s} + C_6H_5CH_3 \Rightarrow 7 CO_2 + 36 Fe^{2+} + 94 H_2O$ <i>Toluene oxidation / iron reduction</i>	-667.21	-2792	21.86:1 ^W
$9 H^+ + 4.5 SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4.5 H_2S^0 + 4 H_2O$ <i>Toluene oxidation / sulfate reduction</i>	-142.86	-597.7	4.7:1
$5 H_2O + C_6H_5CH_3 \Rightarrow 2.5 CO_{2,g} + 4.5 CH_4$ <i>Toluene oxidation / methanogenesis</i>	-34.08	-142.6	0.78:1 ^W

TABLE 4.4 (CONCLUDED)
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Coupled Ethylbenzene Oxidation reactions	ΔG°_r (kcal/mole Ethyl- benzene)	ΔG°_r (kJ/mole Ethyl- benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>Ethylbenzene oxidation / aerobic respiration</i>	-1066.13	-4461	3.17:1
$8.4 NO_3^- + 8.4 H^+ + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>Ethylbenzene oxidation / denitrification</i>	-1080.76	-4522	4.92:1
$84 H^+ + 42 Fe(OH)_{3,s} + C_6H_5C_2H_5 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>Ethylbenzene oxidation / iron reduction</i>	-778.48	-3257	22:1 ^a
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^o + 5 H_2O$ <i>ethylbenzene oxidation / sulfate reduction</i>	-166.75	-697.7	4.75:1
$5.5 H_2O + C_6H_5C_2H_5 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>Ethylbenzene oxidation / methanogenesis</i>	-39.83	-166.7	0.79:1 ^b

Coupled m-Xylene Oxidation Reactions	ΔG°_r (kcal/mole m-xylene)	ΔG°_r (kJ/mole m-xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>m-Xylene oxidation / aerobic respiration</i>	-1063.25	-4448	3.17:1
$8.4 NO_3^- + 8.4 H^+ + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>m-Xylene oxidation / denitrification</i>	-1077.81	-4509	4.92:1
$84 H^+ + 42 Fe(OH)_{3,s} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>m-Xylene oxidation / iron reduction</i>	-775.61	-3245	22:1 ^a
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^o + 5 H_2O$ <i>m-Xylene oxidation / sulfate reduction</i>	-163.87	-685.6	4.75:1
$5.5 H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>m-Xylene oxidation / methanogenesis</i>	-36.95	-154.6	0.79:1 ^b

^a Mass of ferrous iron produced during microbial respiration.

^b Mass of methane produced during microbial respiration.

the subsurface favor use of these electron acceptors or processes. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Environmental conditions and microbial competition ultimately determine which processes will dominate. Vroblesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

The May 1996 groundwater samples were analyzed for the geochemical parameters listed in Table 2.1. Results for these analyses are presented in Table 4.5. Site groundwater data for DO suggest that intrinsic remediation of hydrocarbons in the shallow aquifer is occurring by aerobic biodegradation. In addition, data for sulfate, nitrate/nitrite and methane suggest that anaerobic degradation via sulfate reduction, denitrification, and methanogenesis is occurring. Because both site and background concentrations of ferrous iron are very low, iron reduction is not believed to contribute significantly to the attenuation of BTEX in site groundwater. Geochemical parameters for site groundwater are discussed in the following sections.

4.3.2.1 Dissolved Oxygen

DO concentrations measured in groundwater samples from monitoring wells and points in May 1996 ranged from 0.7 mg/L to 9.3 mg/L (Table 4.5). Figure 4.4 is an isopleth map showing the distribution of DO concentrations in groundwater. When compared to the BTEX plume shown on Figure 4.2, these data are a strong indication that aerobic biodegradation of BTEX compounds is occurring at Building 1212. Given that groundwater samples downgradient and cross-gradient from the source area had high DO, it is likely DO is an important electron acceptor at this site.

The stoichiometry of BTEX mineralization to carbon dioxide and water caused by aerobic microbial biodegradation is presented in Table 4.4. The average mass ratio of oxygen to total BTEX is approximately 3.14 to 1. This translates to the mineralization of approximately 0.32 mg of BTEX for every 1.0 mg of DO consumed. With an average site background DO concentration (taken from cross-gradient monitoring wells peripheral to groundwater contamination) of approximately 8.7 milligrams per liter (mg/L) and a decreased DO concentration in the source area of approximately 0.7 mg/L, the shallow groundwater at this site has the capacity to assimilate 2.6 mg/L (2,600 µg/L) of total

TABLE 4.5
GROUNDWATER GEOCHEMICAL ANALYTICAL DATA
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

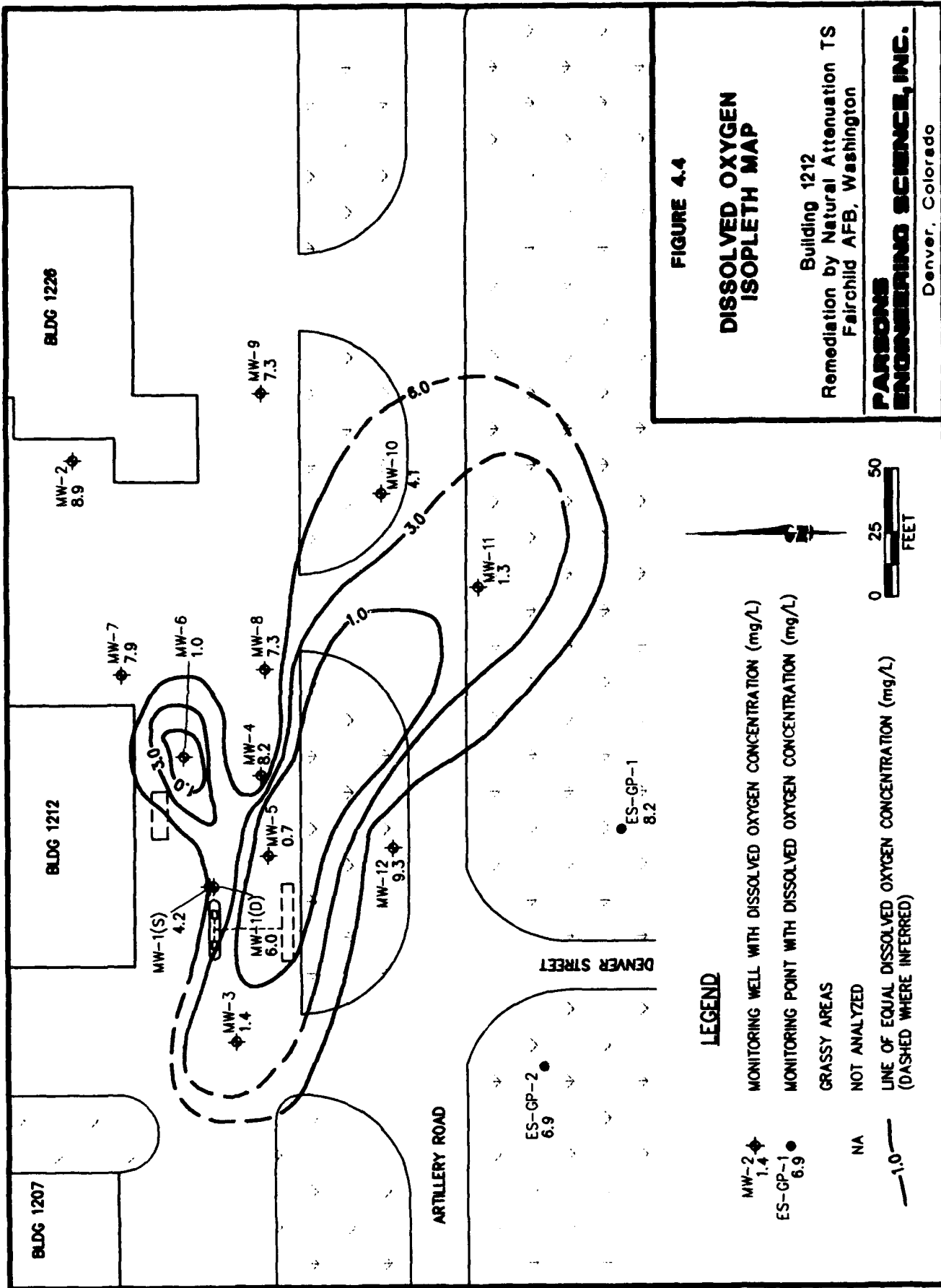
Sample ID	Date Sampled	Temperature (°C) ^{a/}	pH	Conductivity (µs/cm) ^{b/}	Dissolved		Redox		NO ₃ ⁻ + Ferrous				Methane (mg/L)	TOC (mg/L)
					Oxygen (mg/L)	Alkalinity (mg/L)	Potential (mV) ^{c/}	Chloride (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	NO ₃ ⁻ (mg/L)	Iron (mg/L)		
ES-GP1	5/30/96	11.6	9.10	NA ^{d/}	8.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
ES-GP2	5/30/96	16.2	7.60	NA	6.9	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-1(S)	5/29/96	12.5	6.87	450	6.01	920	+30	8.85	6.86	<0.1	<0.05	<0.1	0.013	13.10
MW-1(D)	5/30/96	11.2	6.85	270	4.17	560	+149	5.91	6.87	<0.1	0.08	<0.1	0.011	11.00
MW-2	5/30/96	11.9	7.32	530	8.86	440	+91	103	24.4	<0.1	8.42	<0.1	<0.001	1.27
MW-3	5/29/96	12.3	6.58	450	1.4	540	-3.9	53.9	8.02	0.1	0.27	3.00	0.125	5.71
MW-4	5/29/96	11.2	6.73	330	8.22	620	+94	7.82	18.1	<0.1	0.23	<0.1	0.001	9.90
MW-5	5/29/96	11.5	6.40	210	0.65	440	-121	4.21	3.63	0.2	<0.05	0.90	0.060	5.98
MW-6	5/29/96	12.2	6.67	530	0.99	1160	+5.0	16	18.4	<0.1	0.08	3.20	1.870	14.40
MW-7	5/29/96	12.9	6.78	300	7.88	580	+110	6.49	13.6	<0.1	0.27	<0.1	0.010	2.67
MW-8	5/29/96	11.9	7.16	350	7.33	NA	+74	7.85	59.8	NA	1.72	NA	0.001	6.74
MW-9	5/29/96	12.7	7.06	320	7.26	640	+120	8.02	25.1	<0.1	2.11	<0.1	<0.001	2.16
MW-10	5/29/96	11.4	6.94	290	4.12	580	+119	6.87	30.7	<0.1	1.35	<0.1	<0.001	2.53
MW-11	5/29/96	11.5	6.77	310	1.3	620	+116	6.32	5.37	<0.1	0.92	<0.1	<0.001	2.92
MW-12	5/29/96	10.1	7.02	240	9.26	340	+87	10.4	21.3	<0.1	0.62	<0.1	<0.001	3.55

^{a/} °C = degrees Celsius

^{b/} µs/cm = microsiemens per centimeter

^{c/} mV = millivolts

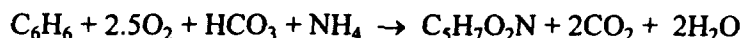
^{d/} NA = Data not available.



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BTEX through aerobic biodegradation. This is a conservative estimate of the assimilative capacity of DO because the recharge of oxygen through upgradient sources has not been considered.

As a microbial population in the groundwater grows in response to the introduction of fuel hydrocarbons into the groundwater, new cell mass is generated. When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given by:



This equation indicates that 5.0 fewer moles of DO are required to mineralize 1 mole of benzene when cell mass production is taken into account. On a mass basis, the ratio of DO to benzene is given by:

Benzene	$6(12) + 1(6) = 78 \text{ gm}$
Oxygen	$2.5(32) = 80 \text{ gm}$

$$\text{Mass Ratio of Oxygen to Benzene} = 80/78 = 1.03:1$$

On the basis of these stoichiometric relationships, 1.03 mg of oxygen are required to mineralize 1 mg of benzene, if cell mass production is taken into account. Similar calculations can be made for toluene, ethylbenzene, and the xylenes. On the basis of these calculations, approximately 0.97 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of DO consumed.

Although this process results in more efficient utilization of electron receptors, it is only applicable as the net cell mass of the microbial population continues to grow. Because groundwater contamination has been present at Building 1212 site for several years, it is expected that biomass mass production is only a small percentage of the overall energy use because the assimilation of BTEX has reached steady-state. Therefore, the cell mass reaction equations would no longer apply, and the assimilative capacity estimate based on no biomass production is considered more accurate. The steady-state production of cell mass as applied to anaerobic mechanisms is also likely, and the following calculations of anaerobic assimilative capacity estimates assume steady-state (i.e., biomass production represents a very small fraction of energy use).

4.3.2.2 Nitrate/Nitrite

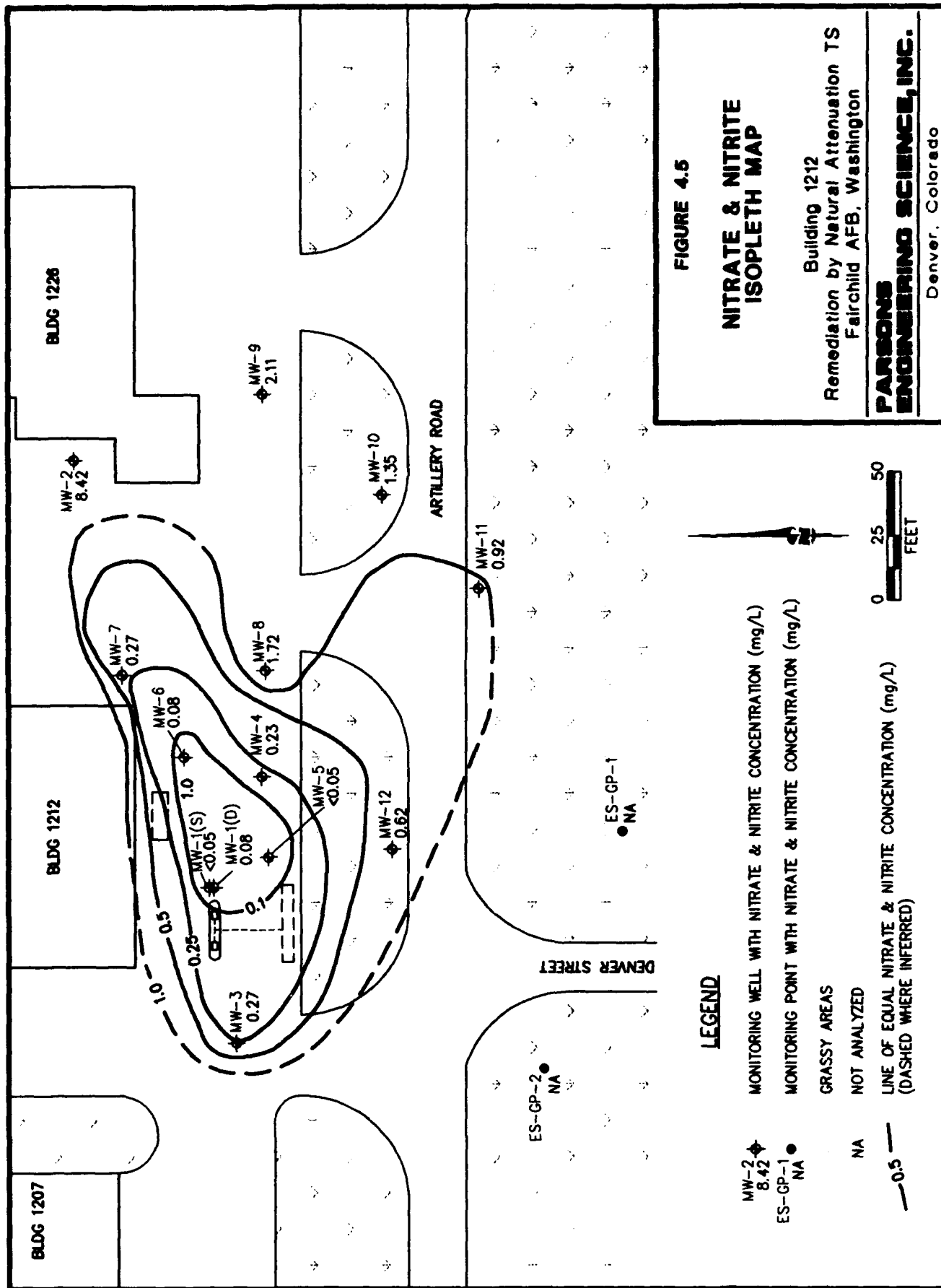
Concentrations of nitrate/nitrite [as nitrogen (N)] were measured in groundwater samples collected in May 1996. Table 4.5 summarizes measured nitrate/nitrite (as N) concentrations. Figure 4.5 presents the distribution of nitrate/nitrite (as N) in groundwater. The data suggest that reduced nitrate/nitrite concentrations correspond to areas of groundwater BTEX contamination, and that nitrate is an electron acceptor at this site. Detectable nitrate/nitrite concentrations at the site ranged from 0.08 to 8.42 mg/L.

In the absence of microbial cell production, the stoichiometry of BTEX mineralization to carbon dioxide, water, and nitrogen caused by denitrification is presented in Table 4.4. The average mass ratio of nitrate to total BTEX is approximately 4.9 to 1. This translates to the mineralization of approximately 0.20 mg of BTEX for every 1.0 mg of nitrate consumed. This ratio of nitrate consumption assumes that nitrate/nitrogen is reported as nitrate ion (NO_3) rather than elemental nitrogen (N). The nitrate nitrogen concentrations shown in Table 4.5 are reported as N, and must be multiplied by 4.42 to be converted into nitrate nitrogen concentrations as NO_3 .

Assuming a background concentration from cross-gradient well MW-2 of 8.4 mg/L (as N) or 37.1 mg/L (as NO_3) and a source area nitrate nitrogen concentration of 0.08 mg/L (as N) or 0.35 mg/L (as NO_3), the shallow groundwater has the capacity to assimilate 7.35 mg/L (7,350 $\mu\text{g/L}$) of total BTEX. Because biomass accumulation is not considered, the actual assimilative capacity attributable to denitrification could be somewhat higher.

4.3.2.3 Ferrous Iron

Ferrous iron (Fe^{2+}) concentrations were measured in groundwater samples collected in May 1996. Table 4.5 summarizes ferrous iron concentrations. Measured ferrous iron concentrations range from <0.1 mg/L to 3.2 mg/L. Only three wells had concentrations of >0.1 mg/L ferrous iron (MW-3, MW-5 and MW-6). No definitive trends were found in measured ferrous iron concentrations, suggesting that iron reduction is not an important attenuation mechanism at Building 1212. However, recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires microbial



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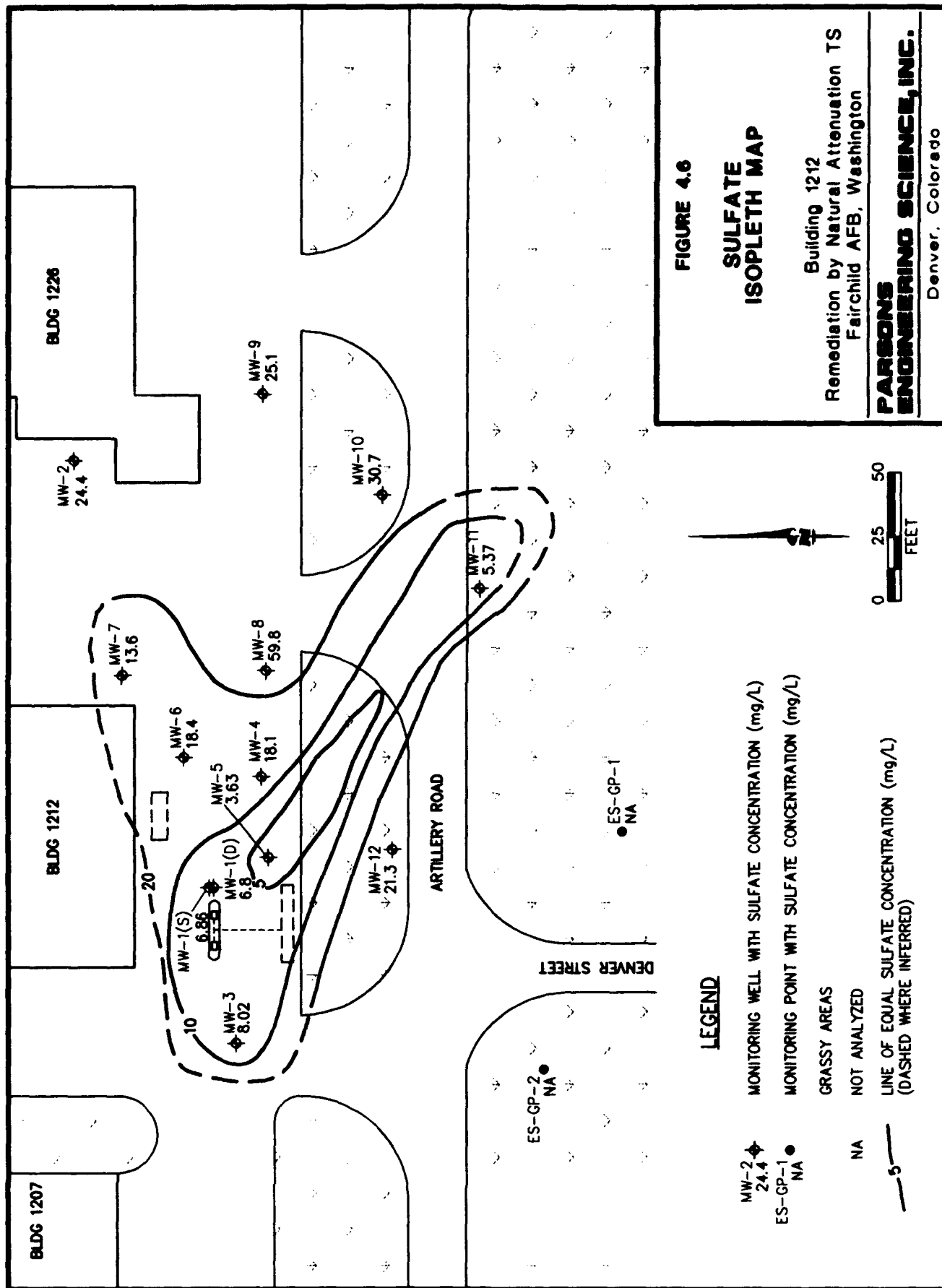
mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in the contaminated groundwater at the site are very strong indicators of microbial activity.

The stoichiometry of BTEX oxidation to carbon dioxide, ferrous iron, and water by iron reduction through anaerobic microbial biodegradation is presented in Table 4.4. On average, 37.5 moles of ferric iron hydroxide are required to metabolize one mole of total BTEX. Conversely, an average of 37.5 moles of ferrous iron are produced for each mole of total BTEX consumed. On a mass basis, this translates to approximately 21.8 mg ferrous iron produced for each 1 mg of total BTEX metabolized. Given a background ferrous iron concentration of approximately 0.1 mg/L and a maximum detected ferrous iron concentration of 3.20 mg/L, the shallow groundwater has the capacity to assimilate approximately 0.08 mg/L (80 µg/L) of total BTEX through iron reduction. This is a conservative estimate of the assimilative capacity of iron because this calculation is based on observed ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer and solid soil matrix. Therefore, iron assimilative capacity could be much higher, but this is doubtful due to the lack of ferrous iron produced in highly contaminated areas at Building 1212.

4.3.2.4 Sulfate

Sulfate concentrations were measured in groundwater samples collected in May 1996. Sulfate concentrations at the site ranged from <0.37 mg/L to 67.40 mg/L. Table 4.5 summarizes measured sulfate concentrations. Figure 4.6 is an isopleth map showing the areal extent of sulfate in groundwater. Comparison of Figures 4.6 and 4.2 shows graphically that the areas of depleted sulfate concentrations coincide with areas of groundwater BTEX contamination. This relationship is a strong indication that anaerobic biodegradation of BTEX compounds is occurring in the shallow groundwater through the microbially mediated process of sulfate reduction.

The stoichiometry of BTEX mineralization to carbon dioxide, sulfur, and water by sulfate reduction through anaerobic microbial biodegradation is presented in Table 4.4. The average mass ratio of sulfate to total BTEX is approximately 4.7 to 1. This translates to the mineralization of approximately 0.21 mg of total BTEX for every 1.0 mg of sulfate consumed. Shallow sulfate concentrations at two clean locations downgradient from the

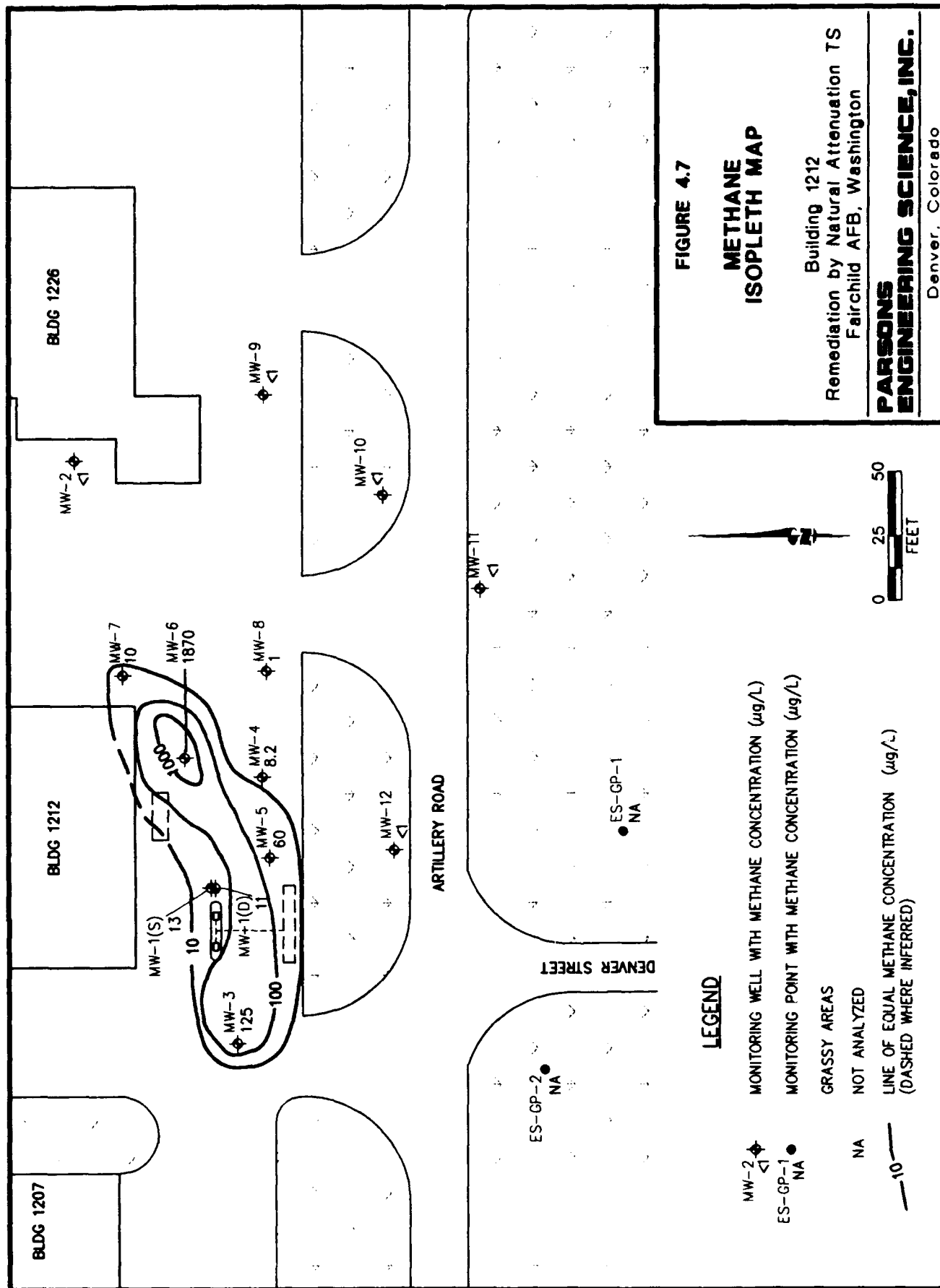


dissolved BTEX plume ranged from 24.4 mg/L to 25.1 mg/L, with an average concentration of 24.8 mg/L. Assuming a background sulfate concentration of 24.8 mg/L and a minimum sulfate concentration in the source area of 3.63 mg/L, the shallow groundwater at this site has the capacity to assimilate 4.5 mg/L (4,500 µg/L) of total BTEX through sulfate reduction.

4.3.2.5 Methane in Groundwater

Methane concentrations were measured in groundwater samples collected in May 1996. Table 4.5 summarizes methane concentrations, which ranged from 0.001 to 1.870 mg/L at the site. Figure 4.7 is an isopleth map showing the distribution of methane in groundwater. Comparison of Figures 4.7 and 4.2 shows graphically that elevated methane concentrations occurred in areas with high dissolved BTEX concentrations. The highest methane concentration was detected at MW-6, which suggests that carbon dioxide becomes a more favorable electron acceptor near the former waste oil tank location.

The stoichiometry of BTEX oxidation to carbon dioxide and methane by methanogenesis is presented in Table 4.4. On average, approximately 1 mg of total BTEX is degraded for every 0.78 mg of methane produced. Given a maximum detected methane concentration of 1.87 mg/L and the assumption of negligible methane concentrations in background groundwater, the shallow groundwater has the expressed capacity to assimilate approximately 2.4 mg/L (2,400 µg/L) of total BTEX through methanogenesis. This is a conservative estimate of the assimilative capacity through methanogenesis because these calculations are based on observed methane concentrations and not on the amount of carbon dioxide (the electron acceptor in methanogenesis) available in the aquifer. Carbon dioxide concentrations were not measured at this site. As methanogenesis produces more carbon dioxide than it consumes (Table 4.4), an unlimited supply of carbon dioxide is theoretically available once the process of methanogenesis has been initiated. Methanogenesis is limited by the rate of reaction rather than the source of electron receptors. This estimate of assimilative capacity also conservatively assumes that all of the produced methane remains in solution; however, this assumption is not realistic as the solubility limit of methane in water is approached.



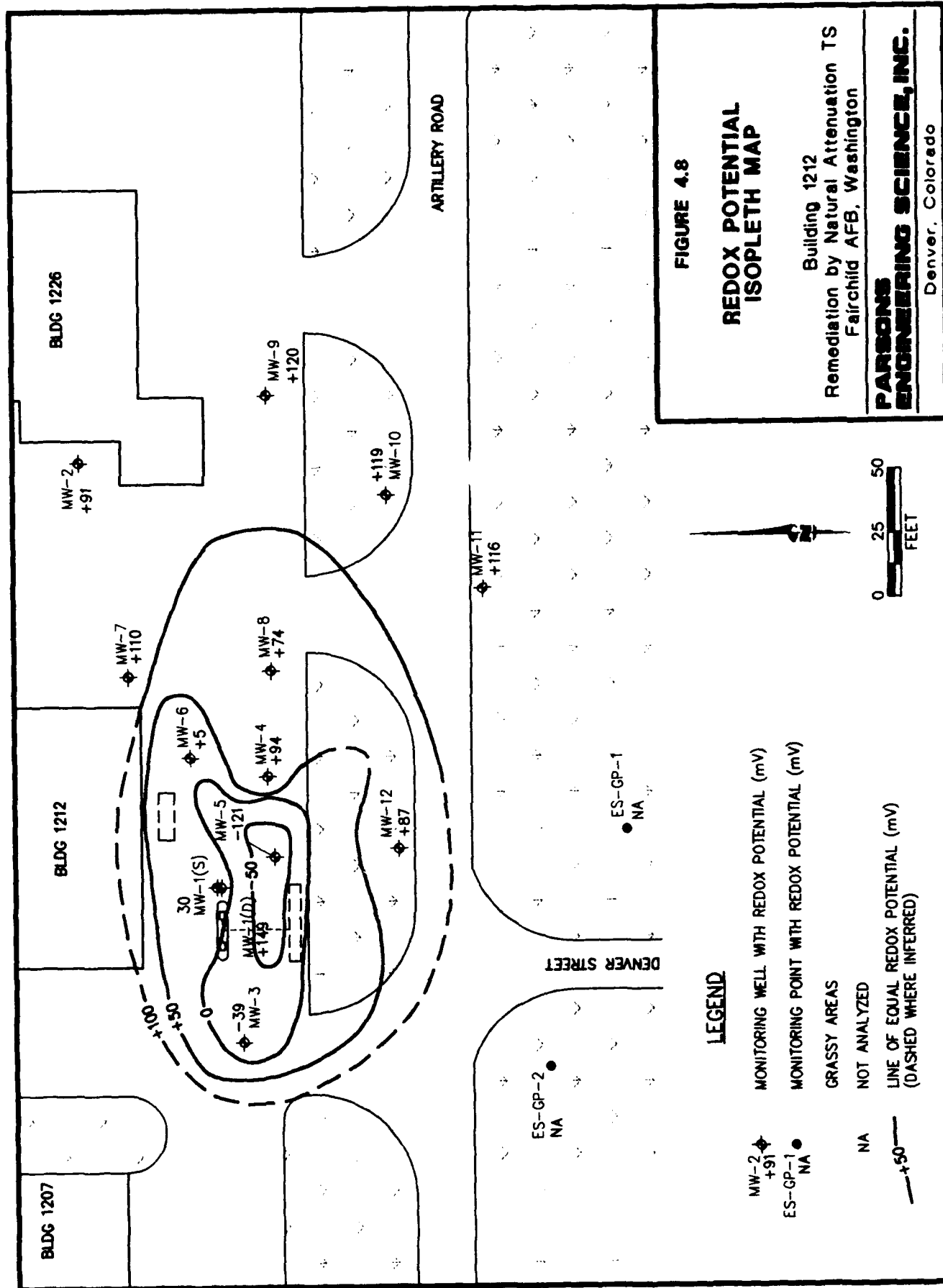
4.3.2.6 Reduction/Oxidation Potential

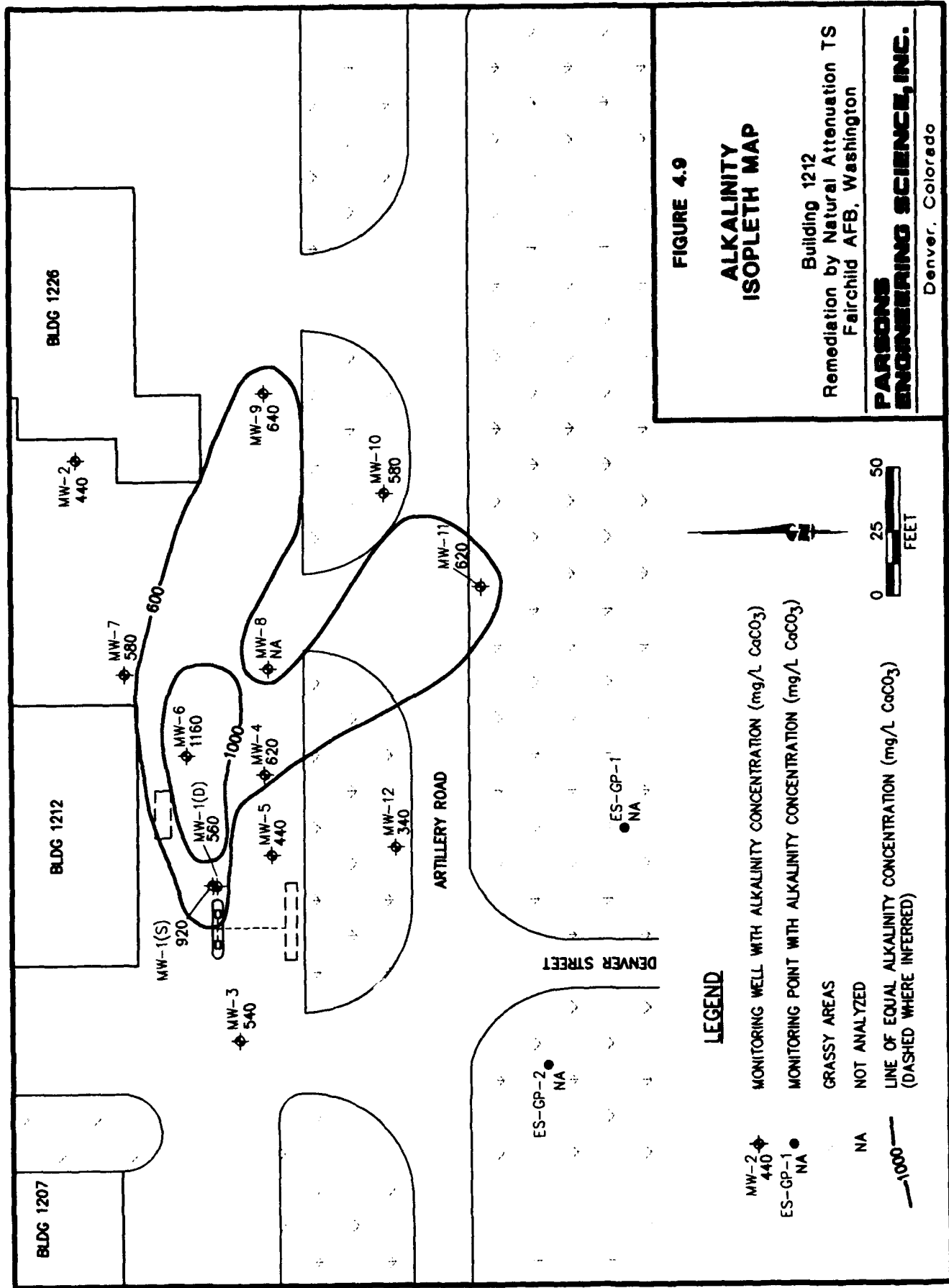
Redox potentials were measured at groundwater monitoring wells and points in May 1996. Redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptors are being reduced by microbes during BTEX oxidation. The redox potentials at the site range from 149 millivolts (mV) to -121 mV. Table 4.5 summarizes available redox potential data. The distribution of redox potential is illustrated graphically on Figure 4.8. As expected, areas at the site with low redox potentials appear to coincide with variable areas of elevated BTEX contamination, decreased oxygen, decreased nitrate/nitrite concentrations, low sulfate concentrations, and methane concentrations (compare Figure 4.8 with Figures 4.2, 4.4, 4.5, 4.6 and 4.7).

4.3.2.7 Alkalinity and Carbon Dioxide Evolution

Carbon dioxide is produced during the bioremediation of petroleum hydrocarbons. In aquifers that have carbonate minerals as part of the matrix, carbon dioxide forms carbonic acid, which dissolves these minerals, increasing the alkalinity of the groundwater. Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. An increase in alkalinity (measured as CaCO_3) in an area with BTEX concentrations elevated above background conditions can be used to infer the amount of petroleum hydrocarbon destroyed through aerobic respiration, denitrification, ferric iron reduction, and sulfate reduction. In addition, carbon dioxide produced in these aerobic and anaerobic reactions can be cycled in the methanogenic reactions to continue BTEX biodegradation through methanogenesis.

Free carbon dioxide was not measured in groundwater samples collected in May 1996; however, total alkalinity (as CaCO_3) was measured. These measurements are summarized in Table 4.5 and presented on Figure 4.9. Total alkalinity at the site varied from 340 mg/L to 1160 mg/L. This range of alkalinity is sufficient to buffer potential changes in pH caused by biologically mediated BTEX oxidation reactions; therefore, it supports the inference that aerobic and/or anaerobic biodegradation processes are occurring without detrimental shifts in pH. Alkalinity increases were observed in locations characterized by elevated BTEX concentrations and in locations just downgradient of high BTEX contamination. This trend suggests that groundwater contamination is being reduced via natural attenuation mechanisms to CO_2 which then





flows downgradient and is incorporated in the groundwater system as buffer capacity, or alkalinity.

4.3.2.8 pH

pH was measured for groundwater samples collected from groundwater monitoring points and monitoring wells in May 1996. These measurements are summarized in Table 4.5. The pH of a solution is the negative logarithm of the hydrogen ion concentration $[H^+]$. Groundwater pH measured at the site ranges from 6.4 to 9.1 standard units. This range of pH overlaps the optimal range for BTEX-degrading microbes, as supported by alkalinity measurements that suggested that groundwater had sufficient buffering capacity for intrinsic bioremediation. As groundwater pH becomes increasingly acidic, fungi may predominate over bacteria in successfully biodegrading hydrocarbons (Atlas, 1988; Brock *et al.*, 1994).

4.3.2.9 Temperature

Groundwater temperature was measured at groundwater monitoring points and monitoring wells in May 1996. Table 4.5 summarizes groundwater temperature readings. Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. Temperatures in the shallow aquifer varied from 10.1 degrees Celsius ($^{\circ}C$) to 16.2 $^{\circ}C$, with an average of 12.1 $^{\circ}C$. These temperatures are within an optimal range for psychrophilic, hydrocarbon-degrading microorganisms.

4.3.3 Discussion

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of jet fuel and gasoline, including the BTEX compounds (e.g., Jamison *et al.*, 1975; Atlas, 1981, 1984, and 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Barker *et al.*, 1987; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989 and 1990; Cozzarelli *et al.*, 1990; Leahy and Colewell, 1990; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Ball *et al.*, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Edwards *et al.*, 1991 and 1992; Evans *et al.*, 1991a and 1991b; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Hutchins *et al.*, 1991a and 1991b; Beller *et al.*,

1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Biodegradation of fuel hydrocarbons can occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the aquifer and sufficient concentrations of electron acceptors, nutrients, and electron donors such as fuel hydrocarbons, are available to these organisms.

Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps provides strong qualitative evidence of biodegradation of BTEX compounds. Isopleth maps suggest that four electron receptors are particularly active in the biodegradation of BTEX compounds at Building 1212: oxygen, nitrate/nitrite, sulfate, and carbon dioxide (indicated by the presence of methane). Typically, zones of depleted oxygen, elevated methane concentration, depleted sulfate concentration, and depleted nitrate/nitrite concentrations coincide with elevated dissolved BTEX concentrations. At Building 1212, the spatial distributions of electron acceptors and metabolic byproducts vary. This variation likely results from the preference of the fuel-degrading microbes for a specific range of groundwater conditions. Conditions present at any given location may either stimulate or inhibit the various microbes. As noted above, variations in both alkalinity and pH may affect the activity levels of indigenous microbes, although these parameters were shown to be at optimal levels at the site.

4.3.4 Expressed Assimilative Capacity

The data presented in the preceding sections suggest that mineralization of BTEX compounds is occurring through the microbially mediated processes of aerobic biodegradation, denitrification, sulfate reduction, methanogenesis, and, to a limited extent, iron reduction. On the basis of the stoichiometry presented in Table 4.4 and observed background electron acceptors, the expressed BTEX assimilative capacity of groundwater at Building 1212 is at least 16,930 $\mu\text{g/L}$ (Table 4.6).

A closed system with 2 liters of water can be used to help visualize the physical meaning of assimilative capacity. Assume that the first liter contains no fuel hydrocarbons, but it contains fuel degrading microorganisms and has an assimilative capacity of exactly "x" μg of fuel hydrocarbons. The second liter has no assimilative capacity; however, it contains fuel hydrocarbons. As long as these 2 liters of water are kept separate, biodegradation of the fuel hydrocarbons will not occur. If these 2 liters are combined in a closed system,

biodegradation will commence and continue until the fuel hydrocarbons are depleted, the electron acceptors are depleted, or the environment becomes acutely toxic to the fuel degrading microorganisms. Assuming a nonlethal environment, if fewer than "x" μg of fuel hydrocarbons were in the second liter, all of the fuel hydrocarbons will eventually degrade given a sufficient time; likewise, if greater than "x" μg of fuel hydrocarbons were in the second liter of water, only "x" μg of fuel hydrocarbons would ultimately degrade.

TABLE 4.6
EXPRESSED ASSIMILATIVE CAPACITY OF SITE GROUNDWATER
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Electron Acceptor or Process	Expressed BTEX Assimilative Capacity ($\mu\text{g/L}$)
Dissolved Oxygen	2,600
Nitrate	7,350
Iron Reduction	80
Sulfate	4,500
Methanogenesis	2,400
Expressed Assimilative Capacity	16,930

The groundwater beneath Building 1212 is an open system, which continually receives additional electron receptors from upgradient and the percolation of precipitation. This means that the assimilative capacity is not a fixed entity as it is in a closed system, and therefore cannot be compared directly to contaminant concentrations in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. Although the expressed assimilative capacity at this site is larger than the highest measured total BTEX concentration (13,118 $\mu\text{g/L}$), the fate of BTEX in groundwater and the potential impact on receptors is dependent on the relationship between the kinetics of biodegradation and the solute transport velocity (Chappelle, 1994). This significant expressed assimilative capacity is a strong indicator that biodegradation is occurring.

At Building 1212 natural attenuation mechanisms could eliminate all groundwater BTEX contamination if the current concentrations of electron acceptors are maintained. Clean, upgradient groundwater could provide this continuous source of electron acceptors

to the microbial population at Building 1212. Furthermore, the probable contaminant sources (the two gasoline USTs, the heating oil UST, and associated piping) have been removed, and clean soil has been used as fill, preventing future introduction of additional soil and groundwater contamination. Because groundwater advective velocity at Building 1212 is 32.9 feet/year, it is not expected that the BTEX plume will migrate significantly downgradient before total contaminant attenuation occurs. Remediation by natural attenuation of BTEX in groundwater should, therefore, be considered when selecting a final remedial solution for Building 1212.

SECTION 5

GROUNDWATER MODEL

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help estimate degradation rates for dissolved benzene at Building 1212 and to help predict the future migration of these compounds, Parsons ES numerically modeled the fate and transport of the dissolved BTEX plume. The modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of biodegradation, advection, dispersion, and sorption; 2) to assess the potential for exposure of downgradient receptors to contaminant concentrations that exceed regulatory standards intended to be protective of human health and the environment; and 3) to provide further technical support for the evaluation of the RNA option. The models were developed using site-specific data and conservative assumptions about governing physical and chemical processes. Due to the conservative nature of the model input, the reduction in contaminant mass resulting from natural attenuation is expected to exceed model predictions. *This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.*

The Bioplume II code was used to estimate the potential for dissolved BTEX migration and degradation by natural mechanisms operating at Building 1212. The Bioplume II model incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The model is based upon the USGS Method of Characteristics (MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The model was modified by researchers at Rice University to include a biodegradation component that can be activated by a superimposed DO plume. On the basis of the work of Borden and Bedient (1986), the model assumes a reaction between DO and BTEX that is instantaneous relative to the advective groundwater velocity. Bioplume II solves the USGS 2-D solute transport equation twice, once for hydrocarbon concentrations in the aquifer and once for a DO plume. The two plumes are combined using superposition at every particle move to simulate the instantaneous biologically mediated reaction between hydrocarbons and oxygen.

In recent years it has become apparent that anaerobic processes such as denitrification, iron reduction, sulfate reduction, and methanogenesis can be important BTEX degradation mechanisms (Grbic'-Galic', 1990; Beller *et al.*, 1992; Edwards *et al.*, 1992; Edwards and Grbic'-Galic', 1992; Grbic'-Galic' and Vogel, 1987; Lovley *et al.*, 1989; Hutchins, 1991). Because geochemical evidence supports the occurrence of anaerobic biodegradation processes at Building 1212 (Section 4.4.2), the combined processes of aerobic and anaerobic biodegradation were considered in calculating BTEX fate and transport at the site. The following subsections discuss in detail the input parameters, the model assumptions, the model calibration, and the simulation results.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Prior to developing a groundwater model, it is important to determine if sufficient data are available to provide a reasonable estimate of aquifer conditions. In addition, it is important to ensure that any limiting assumptions can be justified. The most important assumption made when using the Bioplume II model is that electron-acceptor-limited biodegradation of fuel hydrocarbons is occurring at the site. The Bioplume II model assumes that the limiting factors for BTEX biodegradation are: 1) the presence of an indigenous hydrocarbon-degrading microbial population, and 2) sufficient background electron acceptor concentrations. Data and information presented in Sections 3 and 4 suggest that oxygen, nitrate, ferric hydroxide, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for aerobic and anaerobic biodegradation of BTEX.

On the basis of the data presented in Section 3, the shallow aquifer is defined vertically by clayey silts overlying a basalt bedrock. Within the basalt, a shallow basalt bedrock aquifer occupies the fractured upper portions of the bedrock layer. The middle region of the shallow basalt flow is more competent with less fracturing and acts as an aquitard. The majority of dissolved BTEX contamination preferentially migrates from the site in the clayey silt overlying the basalt. Leakage through the unconsolidated silt into the upper fractured bedrock is occurring and was incorporated into the model. Lithologic data from soil borings suggest that the base of the shallow unconsolidated aquifer is defined by the top of the basalt bedrock at approximately 20 feet bgs. Changes in groundwater recharge associated with the irrigated grasses, and the estimated increase in hydraulic conductivity southeast of the site, may be responsible for variations in groundwater flow direction across the site. Groundwater enters the site from the northwest. Groundwater elevations suggest that the shallow groundwater at the site flows

to the southeast near the former gasoline USTs and eastward near the fuel dispensers and former heating oil UST (Figure 3.4).

The shallow unconsolidated layer above the basalt bedrock was conceptualized and modeled as a shallow unconfined aquifer composed of clayey silt (Figures 3.2, 3.3, and 3.4). The average saturated thickness of this layer was estimated at 15 feet. The use of a 2-D model is appropriate at the Building 1212 site because the shallow saturated interval (acting as the dominant transport pathway) is relatively thin and homogeneous. Although dissolved BTEX migration appears to be intersecting the basalt bedrock, as indicated by groundwater samples from MW-1(D), any further contaminant migration into the basalt would likely encounter similar contaminant fate and transport conditions.

Dissolved BTEX is known to originate from residual soil contamination present in the shallow soils surrounding the former gasoline and heating oil tanks and the associated underground distribution lines. Soil surrounding the former heating oil tank has been replaced with clean backfill. The remaining contaminated soils have not been remediated. Given the current site use and the replacement of damaged USTs and distribution lines, additional fuel releases are not expected at the site in the future; therefore, only BTEX contamination leaching from current residual fuel contamination in site soils was considered as a continuing source for the dissolution of BTEX into groundwater over time.

5.3 INITIAL MODEL SETUP

The setup for this model was based on available site data. Where site-specific data were not available (e.g., effective porosity), reasonable assumptions for the types of materials that make up the shallow aquifer were made on the basis of widely accepted literature values. The following sections describe the basic model setup. Those Bioplume II model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Grid Design and Boundary Conditions

The maximum grid size for the Bioplume II model is limited to 20 columns by 30 rows. The dimension of each column and row can range from 0.1 to 999.9 feet. A 20- by 30-cell grid was used to model Building 1212. Each grid cell was 15 feet long by 15 feet wide. The grid was oriented so that the 30-cell dimension was parallel to the eastward groundwater flow direction. The grid includes the existing BTEX plume and

encompasses an area of 135,000 square feet (approximately 3.1 acres). The full extent of the model grid is indicated on Figure 5.1.

Model boundaries are mathematical statements that represent hydrogeologic boundaries, such as areas of specified head (i.e., surface water bodies or contour lines of constant hydraulic head) or specified flux. Hydrogeologic boundaries are represented by three mathematical statements that describe the hydraulic head at the model boundaries. These include:

- Specified-head boundaries (Dirichlet condition) for which the head is determined as a function of location and time only. Surface water bodies exhibit constant-head conditions. Specified-head boundaries are expressed mathematically as:

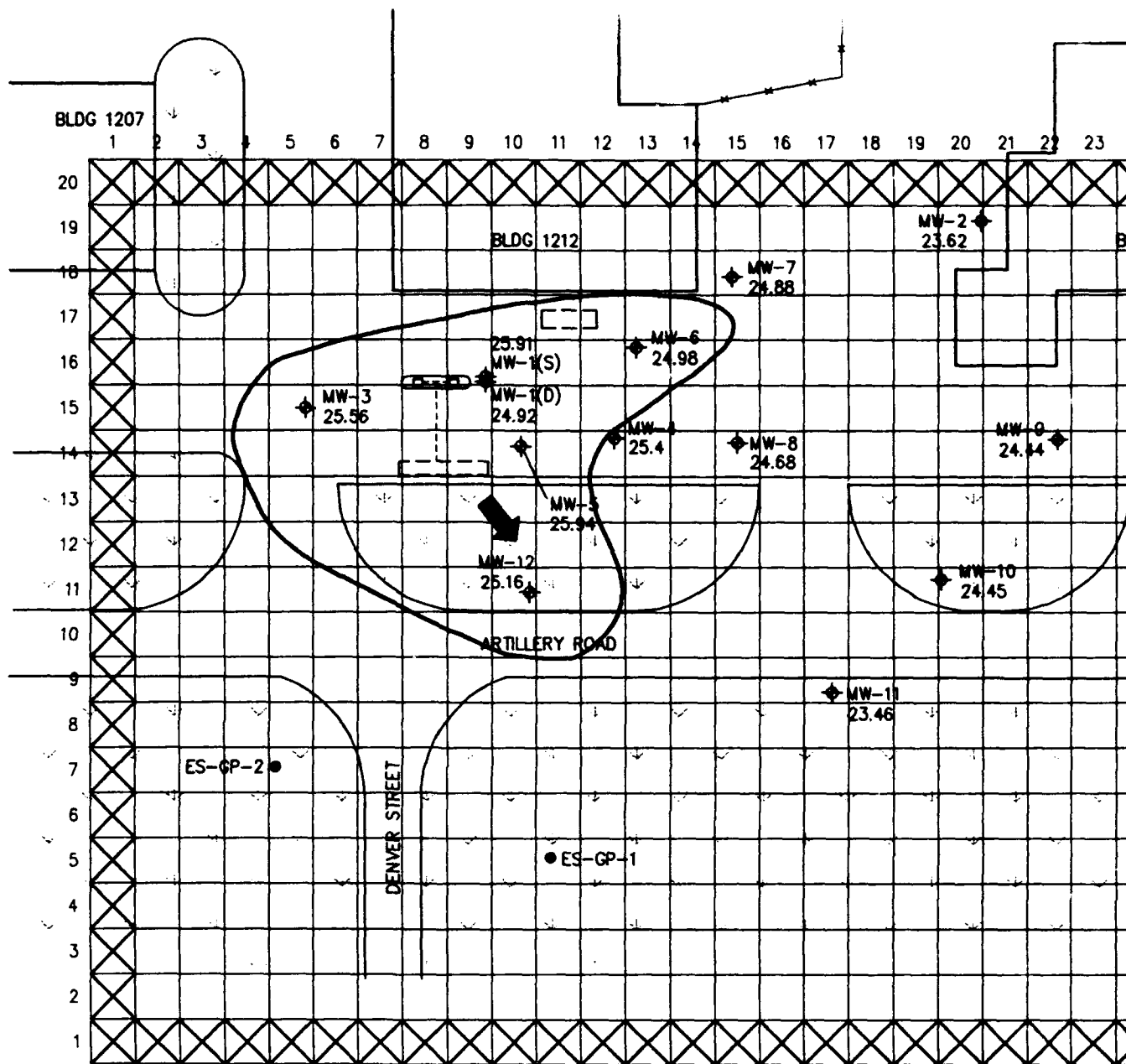
$$\text{Head} = f(x, y, z, t)$$

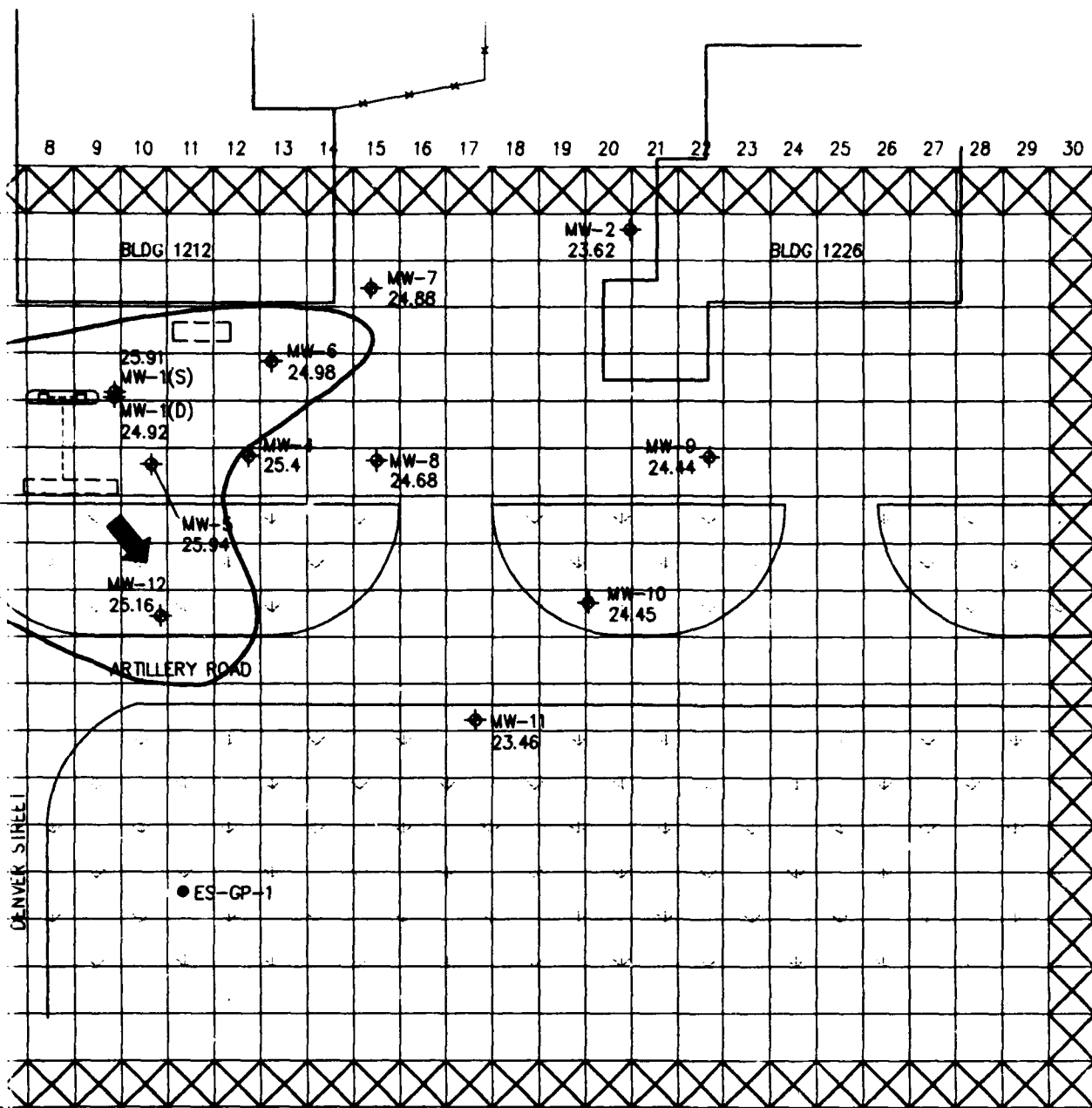
where f is the function symbol, x , y , and z are position coordinates, and t is time.

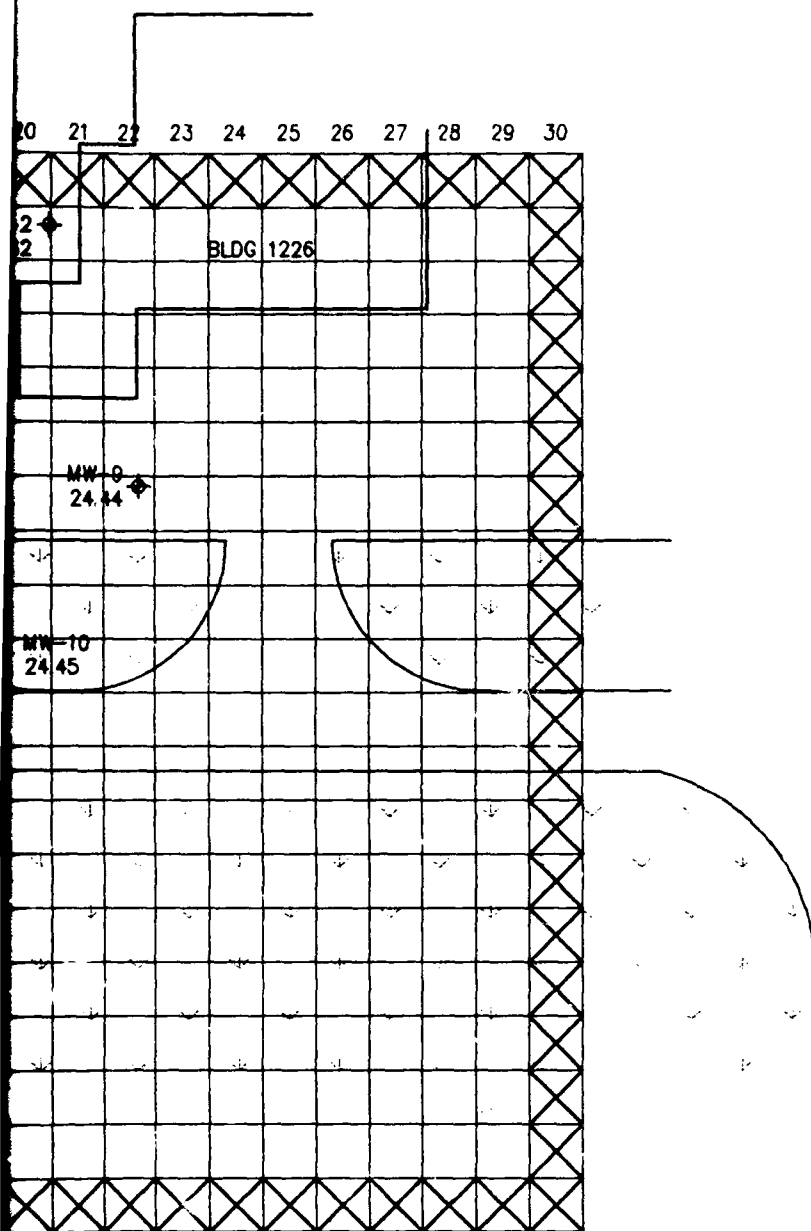
- Specified-flow boundaries (Neumann conditions) for which the mathematical description of the flux across the boundary is given. The flux is defined as a volumetric flow rate per unit area (i.e., ft³/ft²/day). No-flow boundaries are a special type of specified-flow boundary and are set by specifying the flux to be zero. Examples of no-flow boundaries include groundwater divides and impermeable hydrostratigraphic units. Specified-flux boundaries are expressed mathematically as:

$$\text{Flux} = f(x, y, z, t)$$

- 3) Head-dependent flow boundaries (Cauchy or mixed-boundary conditions) where the flux across the boundary is calculated from a given boundary head value. This type of flow boundary is sometimes referred to as a mixed-boundary condition because it is a combination of a specified-head boundary and a specified-flow boundary. Head-dependent flow boundaries are used to model leakage across semipermeable boundaries. Head-dependent flow boundaries are expressed mathematically as (Bear, 1979):







LEGEND







- MW-2  MONITORING WELL
- ES-GP-1  MONITORING POINT
-  GRASSY AREAS
-  APPROXIMATE GROUNDWATER FLOW DIRECTION
-  AREAL EXTENT OF DISSOLVED BTEX, MAY 1996
-  NO-FLOW MODEL CELL



FIGURE 5.1

MODEL GRID

Building 1212
Remediation by Natural Attenuation TS
Fairchild AFB, Washington

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$$Flux = \frac{(H_0 - H)K'}{B'}$$

Where: H = Head in the zone being modeled (generally the zone containing the contaminant plume),
H₀ = Head in external zone (separated from plume by semipermeable layer),
K' = Hydraulic conductivity of semipermeable layer, and
B' = Thickness of semipermeable layer.

Natural hydraulic boundaries are modeled using a combination of the three types of model boundary conditions listed above. When possible, hydrologic boundaries such as surface water bodies, groundwater divides, contour lines, or hydrologic barriers should coincide with the perimeter of the model. In areas lacking obvious hydrologic boundaries, specified-head or specified-flux boundaries can be used at the model perimeter if the boundaries are far enough removed from the contaminant plume that transport calculations are not affected. Bioplume II requires the entire model domain to be bounded by zero-flux cells (also known as no-flow cells), with other boundary conditions established within the subdomain specified by the no-flow cells.

As a result of a lack of natural hydrogeologic boundaries and shifting groundwater flow directions, specified-head boundaries were established on all sides of the model grid. In two-dimensional models, a row of specified-head boundaries at the up- and downgradient ends of the model grid are typically sufficient to simulate the flow of groundwater for sites that are not hydrogeologically complex or are bounded by adjacent lakes or streams. The head at the western boundary was estimated to be from 2424.7 to 2425.9 feet above msl, and represents the level of groundwater in this portion of the site in July 1996. Six model boundary cells in the northwest corner of the model grid had estimated heads ranging from 2425.7 to 2426.0 feet msl and simulated the northwestern component of groundwater flow. The heads along the eastern model boundary ranged from 2422.7 to 2423.0 feet msl.

The base or lower boundary of the model is assumed to be no-flow, and is defined by the upper surface of the basalt bedrock layer located approximately 20 feet bgs. The upper model boundary is defined by the simulated water table surface.

5.3.2 Groundwater Elevation and Gradient

The July 1996 water table elevation map presented in Figure 3.4 was used to define the heads used as initial input into the Bioplume II model. Groundwater flow in the vicinity of Building 1212 varies from south-southeast to east-northeast, with a gradient range over the modeled area of approximately 0.017 ft/ft to 0.009 ft/ft. Gradients are lowest in the vicinity of the source area and highest in the downgradient near monitoring wells MW-10 and MW-11.

5.3.3 BTEX Concentrations

As noted in Section 5.2, dissolved BTEX enters groundwater at Building 1212 through two ongoing processes: contact between groundwater and residual LNAPL at or below the water table in the source area, and migration of recharge (precipitation) through soil containing residual LNAPL above the water table. The total dissolved BTEX concentrations obtained from laboratory analytical results for each well and monitoring point location were used for model development. At the source area well cluster, the higher BTEX concentration [MW-1(S)] was selected to represent concentrations in the shallow aquifer. Table 4.3 presents dissolved BTEX concentration data. Figure 4.2 shows the areal distribution of dissolved BTEX compounds in shallow groundwater.

5.3.4 Biodegradation Rates

Available data strongly suggest that anaerobic degradation is occurring at the site, with combined anaerobic processes accounting for about 85 percent of the BTEX assimilative capacity of site groundwater (Table 4.6). Anaerobic degradation must therefore be simulated with Bioplume II to make meaningful predictions. The Bioplume II model simulates anaerobic biodegradation by assuming that such degradation follows first-order kinetics. As with a large number of biological processes, anaerobic biodegradation can generally be described using a first-order rate constant and the equation:

$$\frac{C}{C_0} = e^{-kt}$$

Where: C = Contaminant Concentration at Time t,
C₀ = Initial Contaminant Concentration,
k = Coefficient of Anaerobic Decay (anaerobic rate constant),
t = time.

Buscheck and Alcantar (1995) derive a relationship that allows calculation of first-order decay rate constants for steady-state plumes. This method involves coupling the regression of contaminant concentration (plotted on a logarithmic scale) versus distance downgradient (plotted on a linear scale) to an analytical solution for one-dimensional, steady-state, contaminant transport that includes advection, dispersion, sorption, and biodegradation (Bear, 1979). For a steady-state plume, the first-order decay rate is given by (Buscheck and Alcantar, 1995):

$$\lambda = \frac{v_c}{4\alpha_x} \left(\left[1 + 2\alpha_x \left(\frac{k}{v_x} \right) \right]^2 - 1 \right)$$

Where: λ = first-order decay rate,

v_c = retarded contaminant velocity in the x-direction,

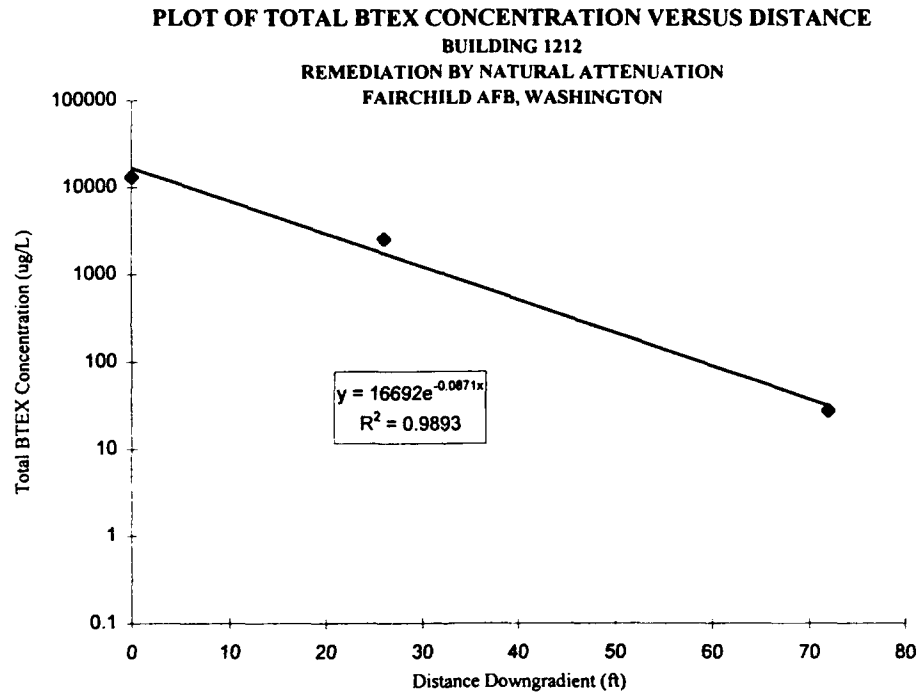
α_x = dispersivity, and

k/v_x = slope of line determined from a log-linear plot of contaminant concentration versus distance downgradient along flow path.

The first-order decay rate includes biodegradation resulting from both aerobic and anaerobic processes; however, in the absence of oxygen, the first-order rate is equivalent to the anaerobic decay rate. Table 5.1 presents a first-order rate constant calculation for BTEX using May 1996 data at Building 1212 and the method proposed by Buscheck and Alcantar (1995). A south-southeasterly groundwater flow path through sampling locations MW-1(S), MW-5, and MW-12 was used for estimating a biodegradation rate. This flow path represents a groundwater travel path from the anaerobic plume core to the more aerobic downgradient extents. An exponential fit to the data estimates a log-linear slope of 0.087 foot^{-1} which was in turn used to estimate a decay constant of 0.013 day^{-1} . The calculated correlation coefficient of 0.989 demonstrates that the use of a first-order biodegradation rate is acceptable.

TABLE 5.1
FIRST-ORDER RATE CONSTANT CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
BUILDING 1212
REMEDATION BY NATURAL ATTENUATION
FAIRCHILD AFB, WASHINGTON

Point	Distance	Total BTEX (µg/L)
	Downgradient(ft)	May-95
MW-1S	0	13118
MW-5	26	2530.4
MW-12	72	27.6



$$\lambda = v_e/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where $v_e = 0.077$ ft/day
 $\alpha_x = 10$ ft
 $k/v = 0.0871$ ft⁻¹
therefore $\lambda = 0.013$ day⁻¹

A review of recent literature indicates that similar anaerobic rate constants generally have been calculated at other sites. For example, Chapelle (1994) reported that at two different sites with anaerobic groundwater conditions, the anaerobic rate constants were both approximately 0.01 day^{-1} . Wilson *et al.* (1994) reported first-order anaerobic biodegradation rates of 0.05 to 1.3 week^{-1} (0.007 to 0.185 day^{-1}); Buscheck *et al.* (1993) report first-order attenuation rates in a range of 0.001 to 0.01 day^{-1} ; and Stauffer *et al.* (1994) report rate constants of 0.01 and 0.018 day^{-1} for benzene and *p*-xylene, respectively. In the groundwater model, a calibrated anaerobic rate constant of 0.007 day^{-1} was used for this site and is within the acceptable data range reported in the literature. Therefore, this selected biodegradation rate is considered to be reasonable.

5.3.5 Dispersivity

Much controversy surrounds the concepts of dispersion and dispersivity. Longitudinal dispersivity values for saturated deposits similar to those found at the site range from 0.1 to 200 feet (Walton, 1988). Longitudinal dispersivity was estimated as 10 feet, using approximately one-tenth (0.1) of the length of the plume from the source area to the downgradient extent (Figure 4.2). Transverse dispersivity values generally are estimated as one-tenth (0.1) of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

During plume calibration, longitudinal dispersivity was maintained at 10 feet. This value is low to moderate compared to possible values given in the literature (Walton, 1988). The use of a lower dispersivity value is a conservative estimate for modeling because low dispersivities cause less BTEX to be lost to dilution. At the same time, the ratio of transverse dispersivity to longitudinal dispersivity was maintained at 0.1 to reproduce the plume width observed at the site.

5.3.6 Coefficient of Retardation

Retardation of the BTEX compounds relative to the advective velocity of the groundwater occurs when BTEX molecules are sorbed to the aquifer matrix. The coefficients of retardation for the BTEX compounds were calculated on the basis of measured TOC concentrations for soils collected at uncontaminated boreholes in and near the saturated zone at the site, an assumed bulk density of 1.65 grams per cubic centimeter (g/cc) (Domenico and Schwartz, 1990), and published values of the soil sorption coefficients (K_{oc}) for the BTEX compounds, as listed by Wiedemeier *et al.* (1995). The results of these calculations are summarized in Table 5.2.

TABLE 5.2
CALCULATION OF RETARDATION COEFFICIENTS
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Compound	K _{oc} (L/kg ^a)	Average Fraction Organic Carbon ^b	Distribution		Bulk Density (kg/L) ^d	Effective Porosity ^a	Coefficient of Retardation Average	Advective		Contaminant Velocity (ft/day)	Contaminant Velocity (ft/year)
			Coefficient K _d (L/kg) Average ^d	Average ^c				Groundwater Velocity (ft/day) ^a			
Benzene	79	0.0005	0.040		1.65	0.15	1.43	0.1096	0.07640		28
Toluene	190	0.0005	0.095		1.65	0.15	2.05	0.1096	0.05359		20
Ethylbenzene	468	0.0005	0.234		1.65	0.15	3.57	0.1096	0.03067		11
m-xylene	405	0.0005	0.203		1.65	0.15	3.23	0.1096	0.03396		12
o-xylene	422	0.0005	0.211		1.65	0.15	3.32	0.1096	0.03300		12
p-xylene	357	0.0005	0.179		1.65	0.15	2.96	0.1096	0.03698		13

NOTES:

^{a/} From technical protocol document (Wiedemeier *et al.*, 1995) and
Groundwater Chemical Desk Reference (Montgomery and Welkom, 1990).

^{b/} From site data.

^{c/} K_d = Average Fraction Organic Carbon x K_{oc}.

^{d/} Literature values.

TOC analyses often are influenced by the presence of soil contamination, which may cause high soil TOC concentrations without necessarily reflecting an increase in the sorptive potential of soil. Therefore, TOC measurements used for retardation estimates should be taken from contaminant-free soils. Furthermore, TOC values should be measured across the water table rather than in the vadose zone to best represent the sorptive potential of saturated soils in the aquifer. Seven locations were chosen for TOC analyses at Building 1212 (Table 4.1). Of these seven sampling locations, three TOC samples were collected at the target depth outside areas of known contamination: MW-4, MW-6, and MW-7 (Figure 4.1). All three samples were collected near or below the water table and had TOC concentrations ranging from 0.038 to 0.061 percent. Table 5.2 reflects the use of a TOC average for these 3 samples in the calculation of site-specific retardation coefficients. A initial value of 1.43 for the retardation coefficient was used for the BTEX compounds. This is intended to correspond to benzene, which is the least sorptive BTEX compound. In addition, this value will be conservative with respect to the other BTEX compounds because they are more retarded by sorption than benzene.

5.4 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps verify that contaminant loading and transport conditions are being appropriately simulated. The numerical flow model presented herein was calibrated by altering transmissivity and constant-head boundary conditions in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy. After calibration of the flow model, the numerical transport model was calibrated by estimating and adjusting the BTEX source loading and transport parameters in a trial-and-error fashion until the simulated BTEX plume approximated observed field values. Table 5.3 lists input parameters used for the modeling effort. Model input and output files are included in Appendix D.

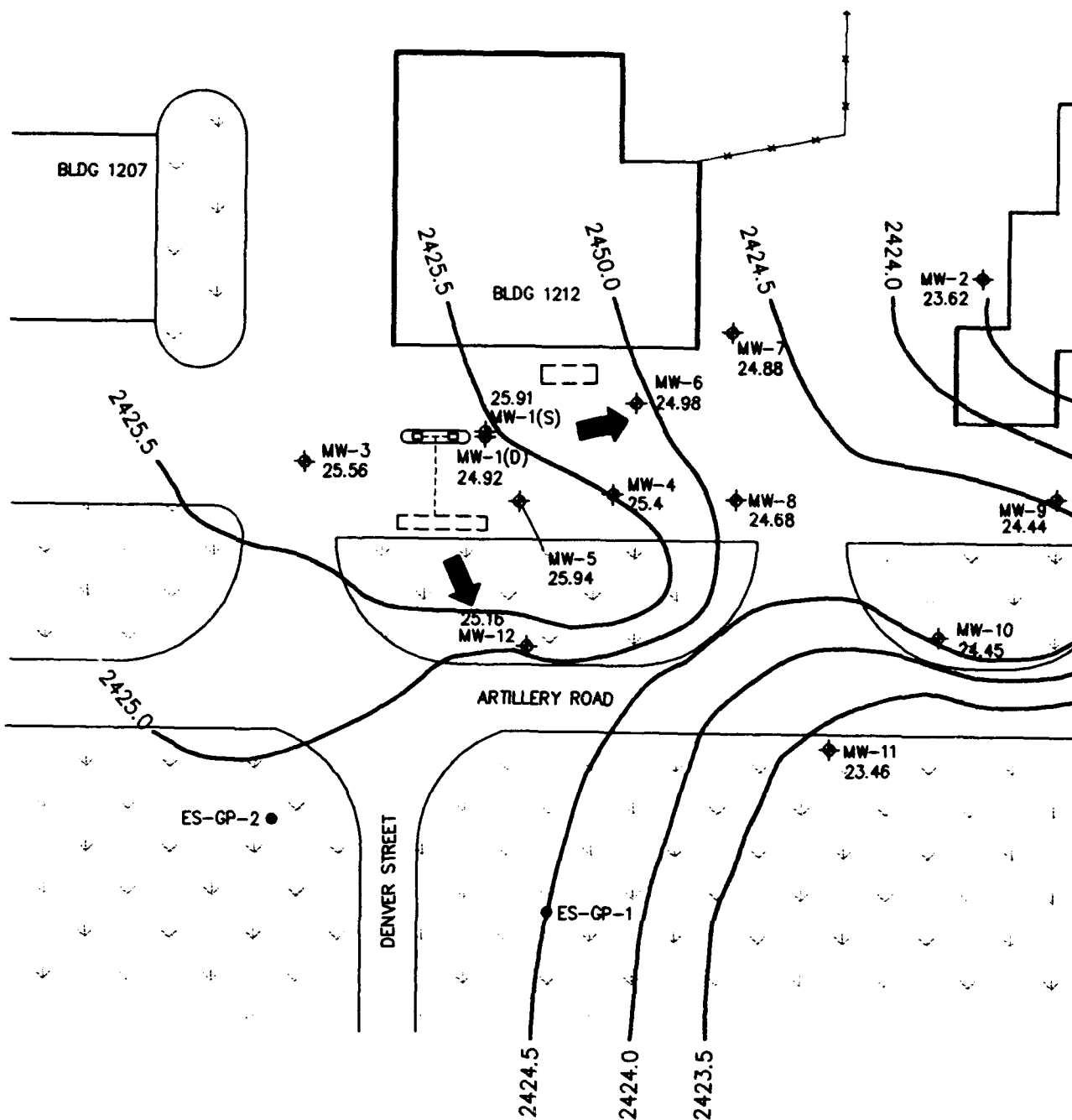
5.4.1 Water Table Calibration

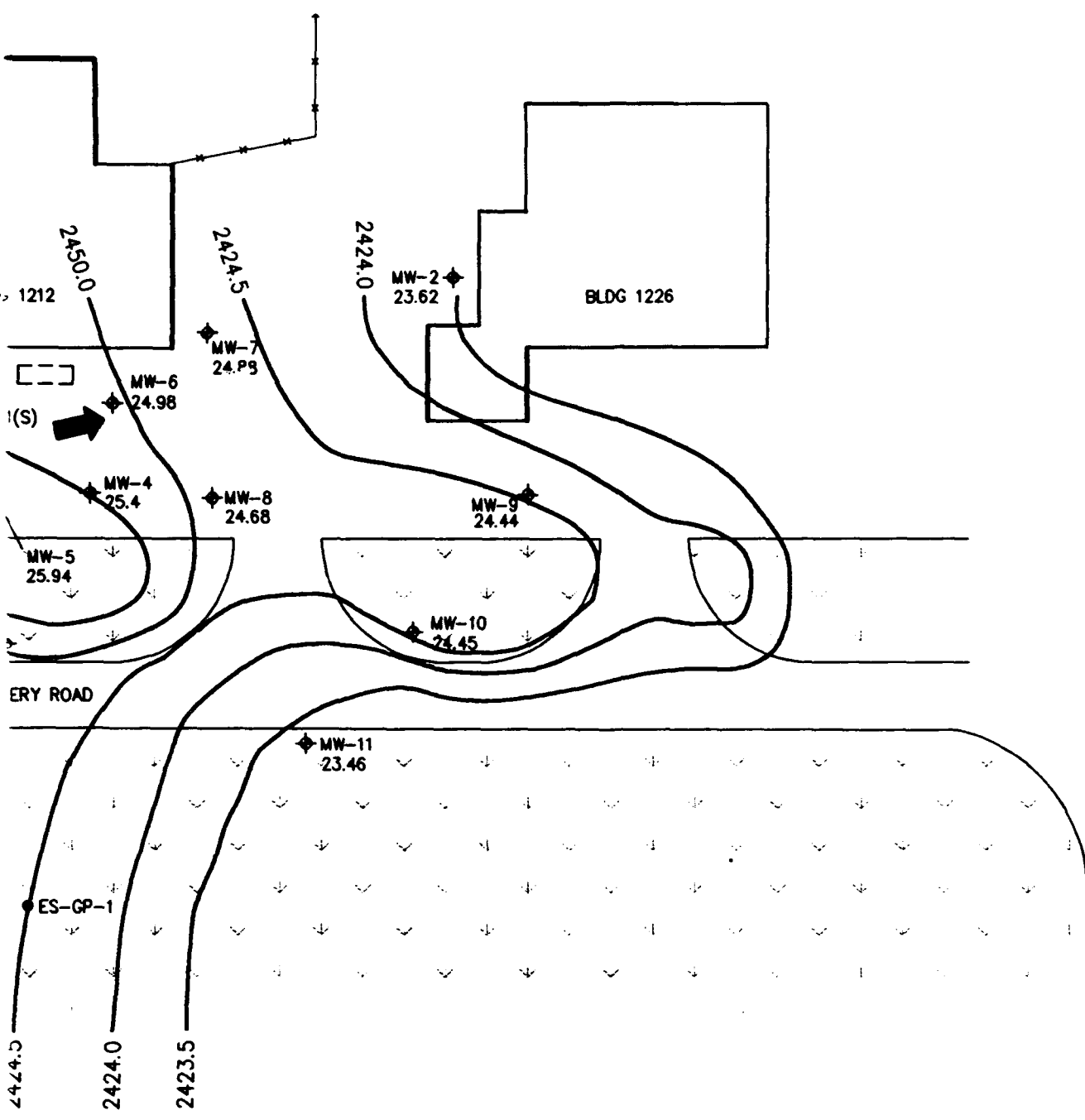
The shallow water table at Building 1212 was assumed to be influenced by continuous recharge and discharge at the constant-head cells surrounding the model grid. The initial water levels at the constant-head cells and the transmissivity values were varied to calibrate the water table surface. The model was calibrated under steady-state conditions.

Hydraulic conductivity is an important aquifer characteristic that determines the ability of the water-bearing strata to transmit groundwater. Transmissivity is the product of the hydraulic conductivity and the thickness of the aquifer. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer and the quantity of electron-acceptor-charged groundwater that is entering the site from upgradient locations. According to the work of Rifai *et al.* (1988), the Bioplume II model is particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume with a relatively small areal extent and a higher average BTEX concentration. Higher values of hydraulic conductivity result in a faster-moving plume that is spread over a larger area and contains lower average BTEX concentrations.

Saturated thickness data from previous reports, geologic logs, and water level measurements were used in conjunction with the hydraulic conductivity estimates to create an initial transmissivity grid for the entire model. To better match heads in the model to observed values, the transmissivities were progressively varied in blocks and rows until the simulated water levels for cells corresponding to selected well locations matched the observed water levels as closely as possible. Figure 5.2 shows the calibrated water table.

Calibrated model hydraulic conductivities ranged from 1.7×10^{-3} foot per second (ft/sec) to 5.0×10^{-6} ft/sec (117.5 ft/day to 0.35 ft/day). This range, spanning nearly 3 orders of magnitude, is appropriate because groundwater flow occurs primarily in silty clay in the source area and in gravelly sand further downgradient. Hydraulic conductivities were varied through this wide range of values using the stratigraphy of the saturated zone as a guide to help achieve a reasonable representation of the observed groundwater table at the site.





LEG

- MW-2 ◆ MO
- ES-GP-1 ● MO
- GR
- API
- FLC
- 2424.0— LIN
- ELE

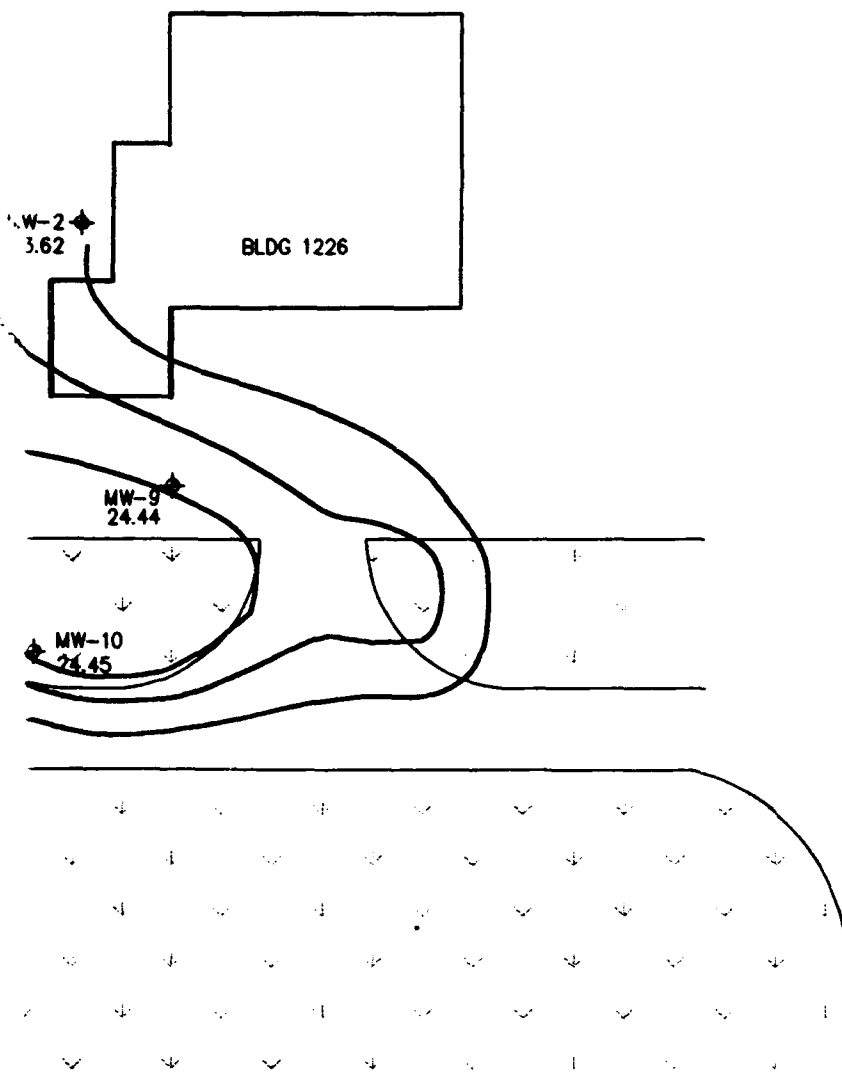
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LEGEND

- MW-2 ◆ MONITORING WELL
- ES-GP-1 ● MONITORING POINT
- GRASSY AREAS
- ➡ APPROXIMATE GROUNDWATER FLOW DIRECTION
- 2424.0— LINE OF EQUAL GROUNDWATER ELEVATION (ft msl)

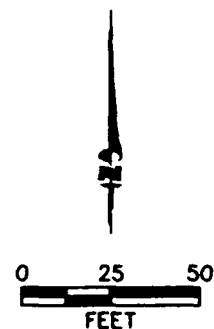


FIGURE 5.2

CALIBRATED GROUNDWATER TABLE

Building 1212
Remediation by Natural Attenuation TS
Fairchild AFB, Washington

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TABLE 5.3
BIOPLUME II MODEL INPUT PARAMETERS
SITE FT-1
REMEDATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Parameter	Description	Calibrated Model Setup	Model RNA	Model Bioventing	Model Excavate
NTIM	Maximum number of time steps in a pumping period	35	35	35	35
NPMP	Number of Pumping Periods	1	22	7	2
NX	Number of nodes in the X direction	20	20	20	20
NY	Number of nodes in the Y direction	30	30	30	30
NPMAX	Maximum number of Particles: $NP_{MAX} = (NX-2)(NY-2)(NPTPND) + (N_s^v)(NPTPND) + 250$	5443	5443	5443	5443
NPNT	Time step interval for printing data	1	1	1	1
NITP	Number of iteration parameters	7	7	7	7
NUMOBS	Number of observation points	0	0	0	0
ITMAX	Maximum allowable number of iterations in ADIP ^w	200	200	200	200
NREC	Number of pumping or injection wells	37	37	37	37
NPTPND	Initial number of particles per node	9	9	9	9
NCODES	Number of node identification codes	1	1	1	1
NPNTMV	Particle movement interval (IMOV)	0	0	0	0
NPNTVL	Option for printing computed velocities	1	1	1	1
NPNTD	Option to print computed dispersion equation coefficients	1	1	1	1
NPDELC	Option to print computed changes in concentration	1	1	1	1
NPNCHV	Option to punch velocity data	0	0	0	0
NREACT	Option for biodegradation, retardation and decay	1	1	1	1
PINT	Pumping period (years)	35	65	50	45
TOL	Convergence criteria in ADIP	0.001	0.001	0.001	0.001
POROS	Effective porosity	0.15	0.15	0.15	0.15
BETA	Characteristic length (long. dispersivity; feet)	50	50	50	50
S	Storage Coefficient	0 (Steady- State)	0 (Steady- State)	0 (Steady- State)	0 (Steady- State)
TIMX	Time increment multiplier for transient flow	-	-	-	-
TINIT	Size of initial time step (seconds)	-	-	-	-
XDEL	Width of finite difference cell in the x direction (feet)	15	15	15	15
YDEL	Width of finite difference cell in the y direction (feet)	15	15	15	15
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.1	0.1	0.1	0.1
CELDIS	Maximum cell distance per particle move	0.5	0.5	0.5	0.5
ANFCTR	Ratio of Tyy to Txx (1 = isotropic)	1	1	1	1
DK	Distribution coefficient	0.04	0.04	0.04	0.04
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.65	1.65	1.65	1.65
THALF	Half-life of the solute	-	-	-	-
DEC1	Anaerobic decay coefficient (day ⁻¹)	0.007	0.007	0.007	0.007
DEC2	Reaeration coefficient (day ⁻¹)	0.0	0.0	0.0	0.0
F	Stoichiometric Ratio of Hydrocarbons to Oxygen	3.14	3.14	3.14	3.14

^v N_s = Number of nodes that represent fluid sources (wells or constant head cells).

^w ADIP = Alternating-direction implicit procedure (subroutine for solving groundwater flow equation).

A precipitation recharge rate of 4.6 inches per year was assumed to enter the aquifer in the grassy areas. This is equivalent to approximately 20 percent of the annual precipitation at Fairchild ARB. This rate may be slightly low because regular irrigation of the grass could increase the infiltration rate; however, it is considered acceptable due to the possible leakage of shallow groundwater into the shallow bedrock. Because Bioplume II is a 2-D groundwater model and does not have vertical aquifer leakage parameters, modeled groundwater recharge was assumed to be equal to the difference between recharge due to precipitation and irrigation, and groundwater loss due to aquifer leakage.

Water level elevation data from cells associated with 12 groundwater monitoring locations were used to compare measured and simulated heads for calibration. The 12 selected cell locations each contained one of the following shallow monitoring wells: MW-1(S), MW-2, MW-3, MW-4, MW-5, MW-6, MW-7, MW-8, MW-9, MW-10, MW-11, and MW-12.

The root mean square (RMS) error is commonly used to express the average difference between simulated and measured heads. RMS error is the average of the squared differences between measured and simulated heads, and can be expressed as:

$$RMS = \left[\frac{1}{n} \sum_{i=1}^n (h_m - h_s)_i^2 \right]^{0.5}$$

Where: n = the number of points where heads are being compared,
 h_m = measured head value (feet above msl), and
 h_s = simulated head value (feet above msl).

The RMS error between observed and calibrated values at the 12 comparison points was 0.16 feet, which corresponds to a calibration error of 4.7 percent (water levels dropped 3.3 feet over the length of the model grid). RMS error calculations are summarized in Appendix C. A plot of measured versus calibrated heads shows a random distribution of points around a straight line, as shown in Appendix C. Deviation of points from a straight line should be randomly distributed in such a plot of results from computer simulations (Anderson and Woessner, 1992).

In solving the groundwater flow equation, Bioplume II establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. Considering the groundwater hydraulics at the site, the hydraulic mass balance for the calibrated model was reasonable,

with 99.85 percent of the water flux into and out of the system being numerically accounted for (i.e., a 0.15-percent error). According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable, while Konikow (1978) indicates an error of less than 0.1 percent is ideal.

5.4.2 BTEX Plume Calibration

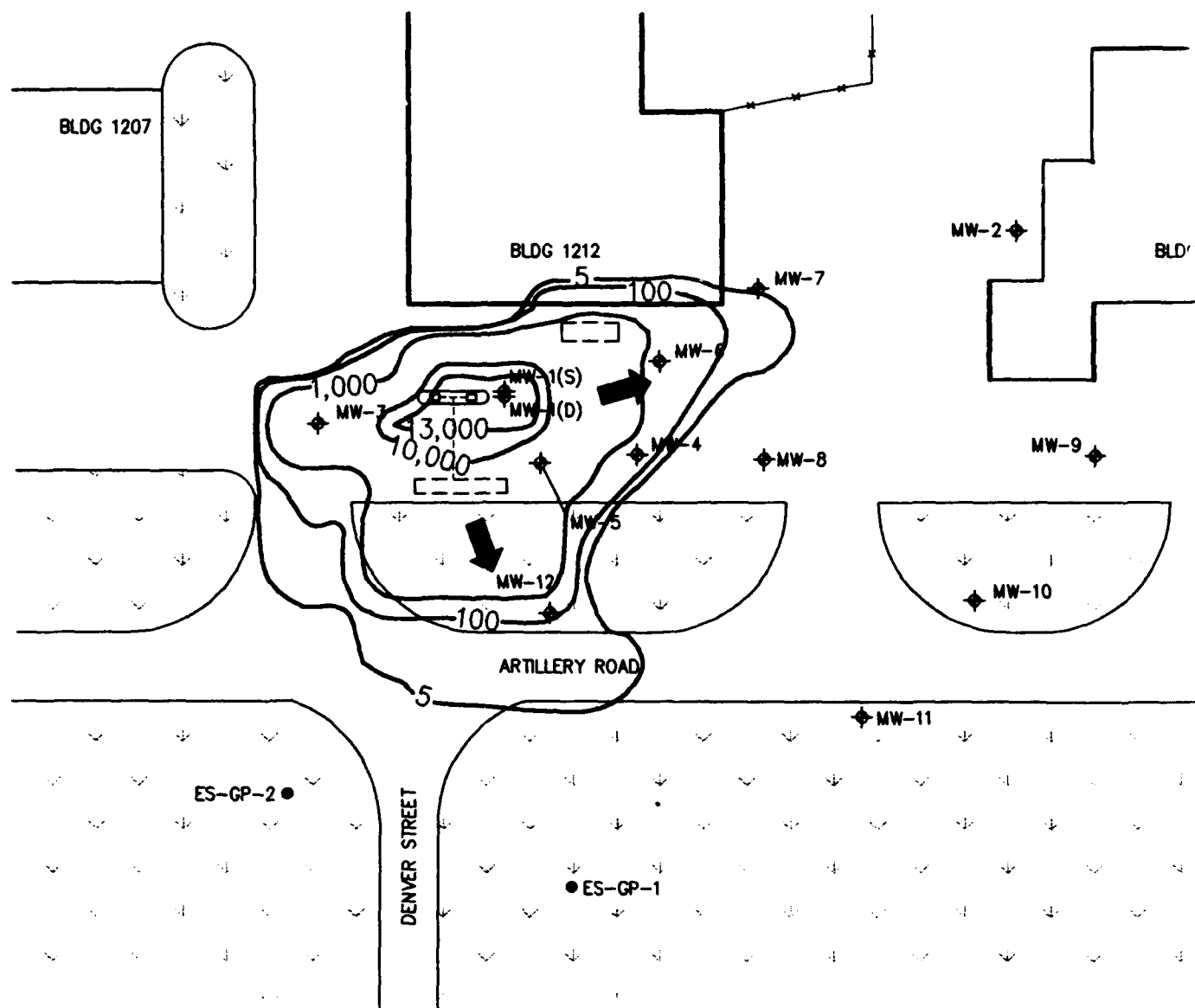
Model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified so that model predictions matched dissolved total BTEX concentrations observed in May 1996. BTEX plume calibration model runs were made using the calibrated steady-state hydraulic parameters coupled with the introduction of contaminants. Because the exact time, type, and frequency of the fuel releases at the site are unknown, the model was calibrated to match May 1996 conditions, assuming the groundwater was first impacted 35 years ago. Fairchild AFB records indicate the 3,000-gallon gasoline tanks were installed in 1948 and remained in use until removal in November 1995 (Budinger and Associates, 1995). The model assumes that fuel leakage from the tanks and associated distribution lines did not occur or impact groundwater until 12 years after installation. One leaching period (1960-1995) was used in the calibration to simulate the configuration of the dissolved BTEX plume resulting from source areas at the Building 1212 site.

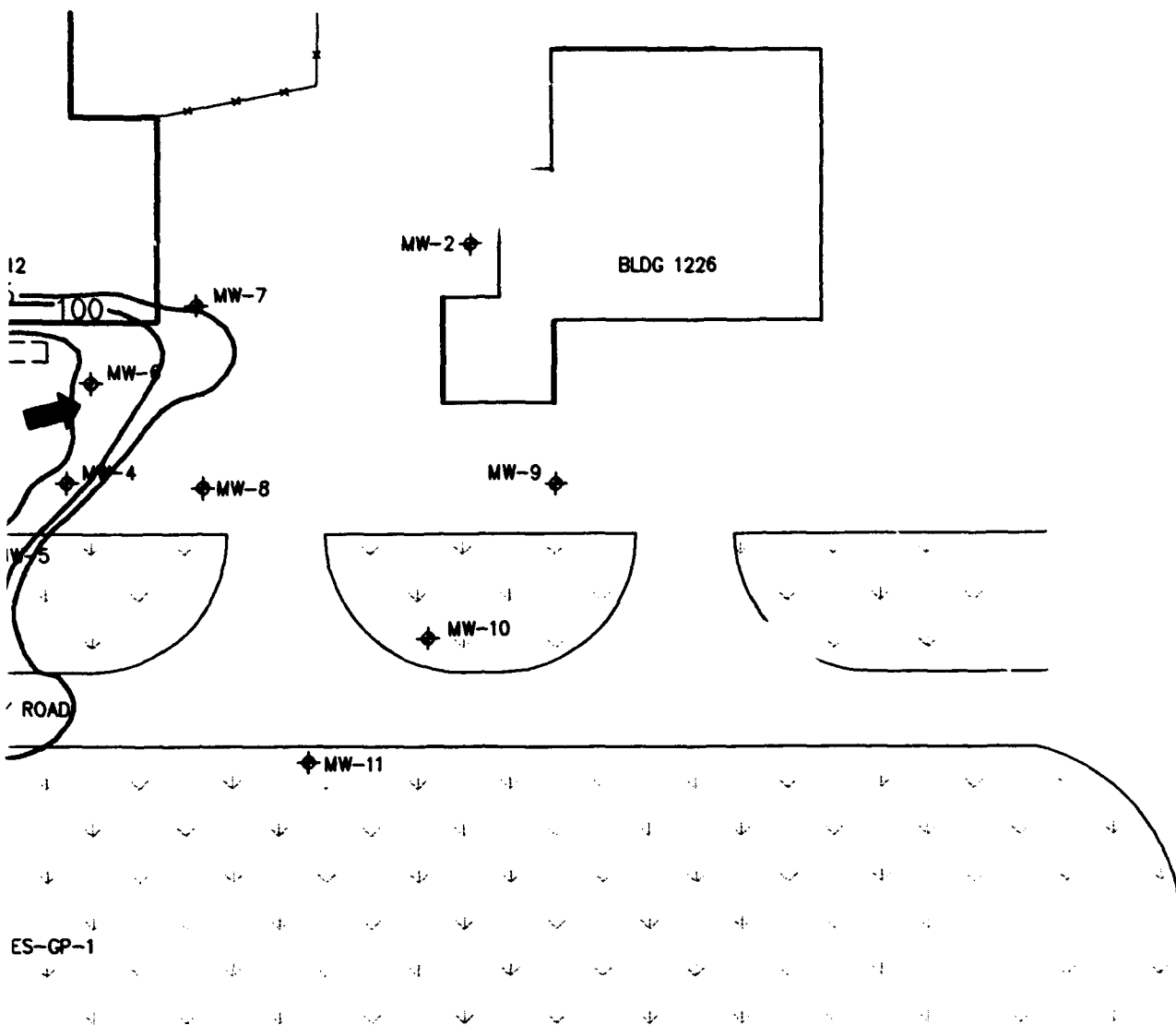
Estimated BTEX source concentrations (Section 5.3.3) were applied to simulated injection wells within 37 model cells situated in the core of area of soil contamination to reproduce the configuration and concentrations of the groundwater BTEX plume (Figure 5.1). While the term "injection well" suggests contaminants are being introduced at a point, Bioplume II assumes that contamination introduced at a well instantly equilibrates throughout the entire cell in which the well is located. The injection rate for the cells varied from 1.2×10^{-7} to 1.2×10^{-8} cubic foot per second (ft³/sec) and did not affect the flow calibration and water balance. Loading rates and periods were varied cell by cell as needed to reproduce the shape of the observed groundwater plume. In this manner, the potential source strength of the residual contamination was maintained while simultaneously obtaining the configuration of the observed BTEX plume (Figure 4.3).

For the modeled 35 years (1960-1995), varying amounts of BTEX were injected at 37 injection wells simulating the area of soil contamination. Without any historical data regarding known fuel releases, the BTEX plume was calibrated using trial and error to simulate the start of contamination and determine approximate source concentrations.

Higher injection rates and concentrations were used in the vicinity of the former heating oil and gasoline tanks and the fuel dispensers to simulate the observed 1996 BTEX concentrations. Lower injection concentrations in the remaining source cells were needed to simulate the plume shape. These injection cells were required because the field soil sample results indicate a widespread area of contamination surrounding the fuel dispensers and former tank locations. This may be the result of leaks and spills migrating both vertically and horizontally in the low hydraulic conductivity soils and fluctuations in the groundwater table.

The objective of the calibration was to achieve a modeled plume that equaled or exceeded the observed plume in terms of extent and concentration, and that effectively simulated the flow of BTEX contaminants from the source areas to the observed downgradient locations. Because the low hydraulic conductivity at Building 1212 slows downgradient plume migration, the contact time with electron acceptors in the aquifer increases and biodegradation mechanisms have a greater affect on the BTEX plume fate. The calibrated dissolved BTEX plume is shown in Figure 5.3. The final calibrated model plume (year 35) was assumed to represent present-day (1996) conditions, and successfully meets these objectives, as it reproduces the observed areal extent and contaminant concentrations (Figure 5.1). The calibrated plume accurately predicts a flow of contamination from the source area toward the east and southeast. In the vicinity of MW-1(S), simulated BTEX concentrations are within .5 percent of the observed concentrations. However, the calibrated model slightly over estimates the BTEX concentration at MW-12. The fact that the model concentrations are slightly higher than observed concentrations means that additional BTEX mass is accounted for in the model simulations, and that model predictions are conservative. Although the 100- $\mu\text{g/L}$ and 1,000- $\mu\text{g/L}$ contours cover a larger areal extent than those presented on Figure 4.2, they also can be considered a reasonable interpretations of observed concentrations. Variations in shape between the model and the observed plume likely are due to subsurface heterogeneities in the hydraulic conductivity, anaerobic decay, dispersivity, and retardation that are extremely difficult to identify in the field and to replicate in a discretized 2-D model domain.





LEGEND

- MW-2 ◆ MONITORING WELL
- ES-GP-1 ● MONITORING WELL
- GRASSY AREA
- ➔ APPROXIMATE FLOW DIRECTION
- 5 — LINE OF CONCENTRATION

0 100

FI

CALIBRA

But
Remediation by
Fairchild

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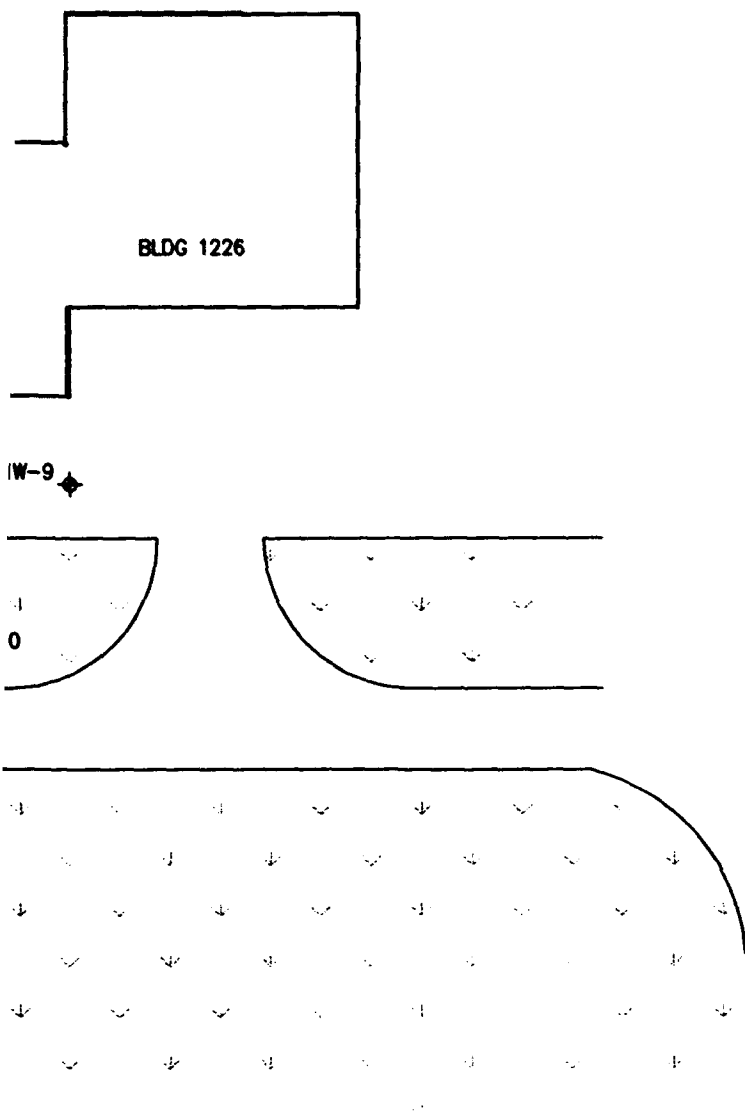


FIGURE 5.3

CALIBRATED BTEX PLUME

Building 1212
Remediation by Natural Attenuation TS
Fairchild AFB, Washington

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5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. According to the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the coefficient of aerobic decay (reaeration coefficient), the coefficient of anaerobic decay, and the hydraulic conductivity of the media, and is less sensitive to changes in the distribution coefficient (retardation factor), effective porosity, and dispersivity. To fully evaluate the sensitivity of the calibrated model, the transmissivity, the coefficient of anaerobic decay, the distribution coefficient, dispersivity, and effective porosity were all varied. The reaeration coefficient was not used in this model.

To perform the sensitivity analyses, the aforementioned parameters were individually and systematically varied; the model was rerun, and the results were compared to the original calibrated model. Each sensitivity model was run for a 35-year period (the same duration used in the original calibrated model) to assess the independent effect of each variable. A total of 10 sensitivity runs of the calibrated model were performed, with the following variations:

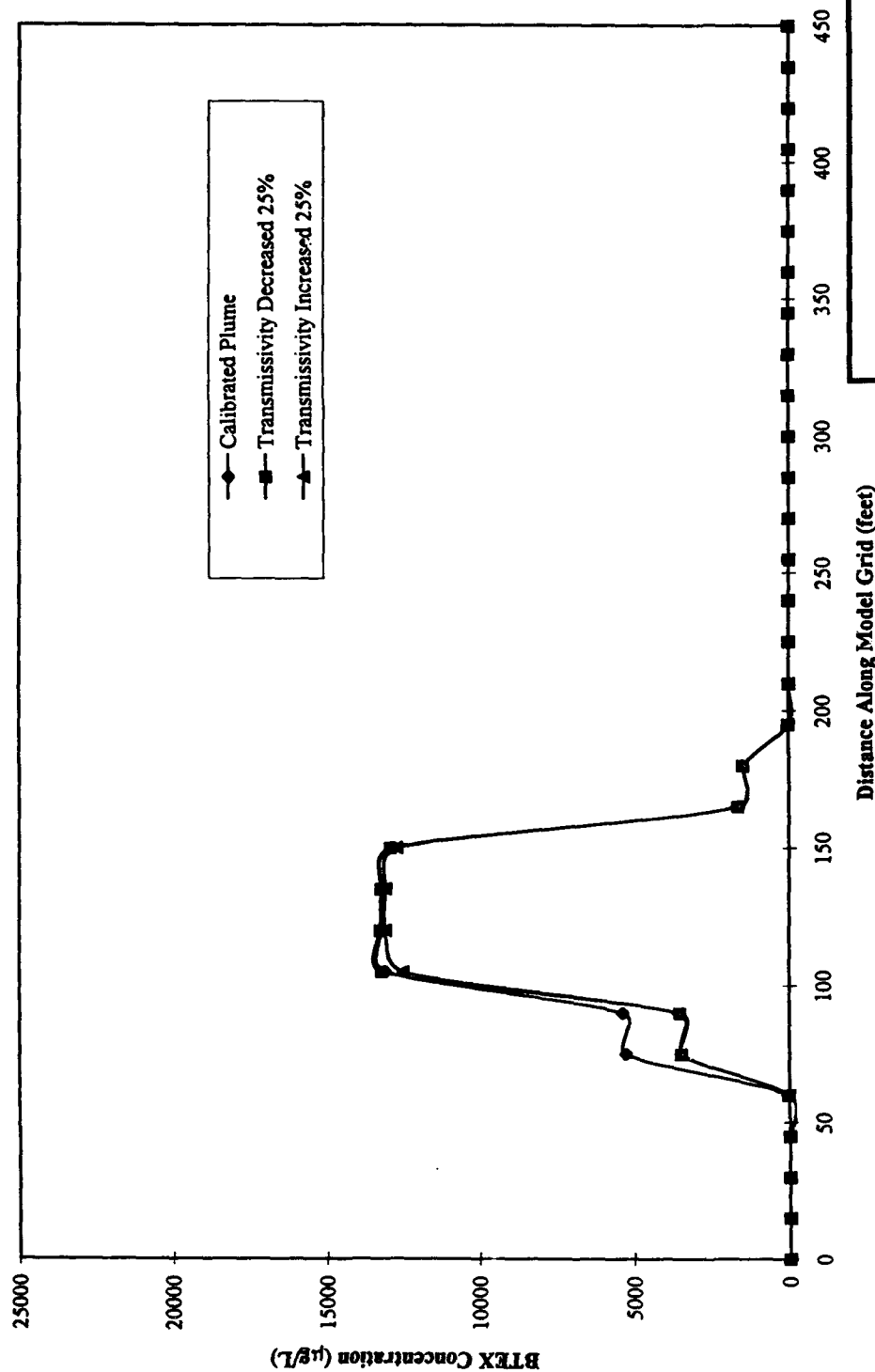
- 1) Transmissivity uniformly increased 25 percent;
- 2) Transmissivity uniformly decreased 25 percent;
- 3) Coefficient of anaerobic decay increased by a factor of 2;
- 4) Coefficient of anaerobic decay decreased by a factor of 2;
- 5) Distribution coefficient increased by 20 percent;
- 6) Distribution coefficient decreased by 20 percent;
- 7) Dispersivity increased by 50 percent;
- 8) Dispersivity decreased by 50 percent;
- 9) Effective porosity increased by 25 percent; and
- 10) Effective porosity decreased by 25 percent.

The results of the sensitivity analyses are shown graphically in Figures 5.4 through 5.8. These figures display simulated BTEX concentrations versus distance downgradient from the source area. This manner of displaying data is useful because changes in BTEX concentrations can be easily visualized.

The effects of varying transmissivity are shown on Figure 5.4. Typically, previous sensitivity models have varied transmissivity values by a factor of 5. However, because of low hydraulic conductivities and high BTEX injection concentrations, an increase in transmissivity values greater than 25 percent of the calibrated value cause the groundwater model to fail. The model failure is the result of computational errors in the Bioplume II mass balance calculations. Uniformly increasing the transmissivity by 25 percent increased groundwater velocity, and therefore decreased the residence time of groundwater in the aquifer. As a result, BTEX concentrations decreased throughout the plume because of increased dilution of the BTEX compounds. When the transmissivity values are increased 25 percent, the maximum observed BTEX concentration in the source area was 13,040 $\mu\text{g/L}$, compared to the calibrated 13,178 $\mu\text{g/L}$. In contrast, decreasing the transmissivity by 25 percent slowed overall plume migration, which increased the maximum BTEX concentrations because of decreased dilution and spreading. The BTEX concentration in the source area increased to approximately 13,215 $\mu\text{g/L}$. The sensitivity of the model to hydraulic conductivity suggests that appropriate transmissivity values were used in the model calibration.

The effects of varying the coefficient of anaerobic decay are illustrated by Figure 5.5. As expected, increasing this parameter by a factor of two results in a smaller plume with a maximum BTEX concentration of 6,700 $\mu\text{g/L}$. Conversely, decreasing the coefficient of anaerobic decay by a factor of two decreases the biodegradation rate and increases plume concentrations. The resultant increase raised computed maximum BTEX concentrations in the source area from 13,178 $\mu\text{g/L}$ to 24,122 $\mu\text{g/L}$. These results show that the calibrated model is sensitive to variations in the coefficient of anaerobic decay and suggest that the coefficient of anaerobic decay calculated by the method of Buscheck and Alcantar (1995) is a reasonable value for the calibrated model.

The effects of varying the distribution coefficient are shown on Figure 5.6. Increasing the distribution coefficient by 20 percent has a significant effect on the contaminant distribution. An increase in sorptive capacity caused a decrease increase of approximately 6,500 $\mu\text{g/L}$ in the source area, producing a maximum BTEX concentration of 6,700 $\mu\text{g/L}$. The decrease in the maximum plume concentration resulted from a slowing of BTEX migration, which allowed for greater BTEX accumulation in the source area. A decrease in concentrations resulted from an increased contact period of the sorbed BTEX with electron acceptors flushing into the system. Decreasing the distribution coefficient by 20 percent decreases the potential for contact of sorbed BTEX with replenished electron acceptors, thus allowing less biodegradation. As a result, the



Distance Along Model Grid (feet)

FIGURE 5.4

MODEL SENSITIVITY TO VARIATIONS IN TRANSMISSIVITY

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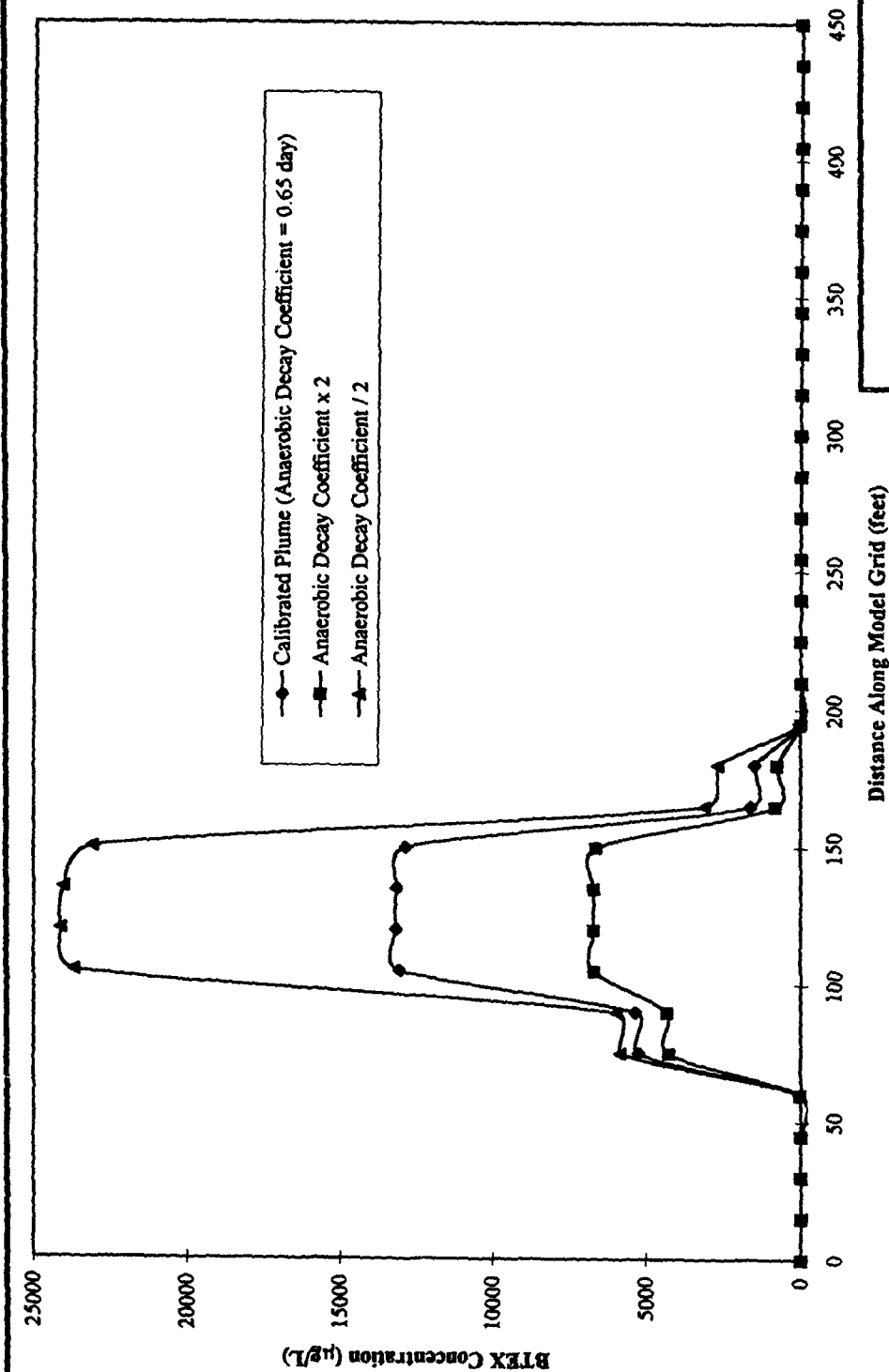
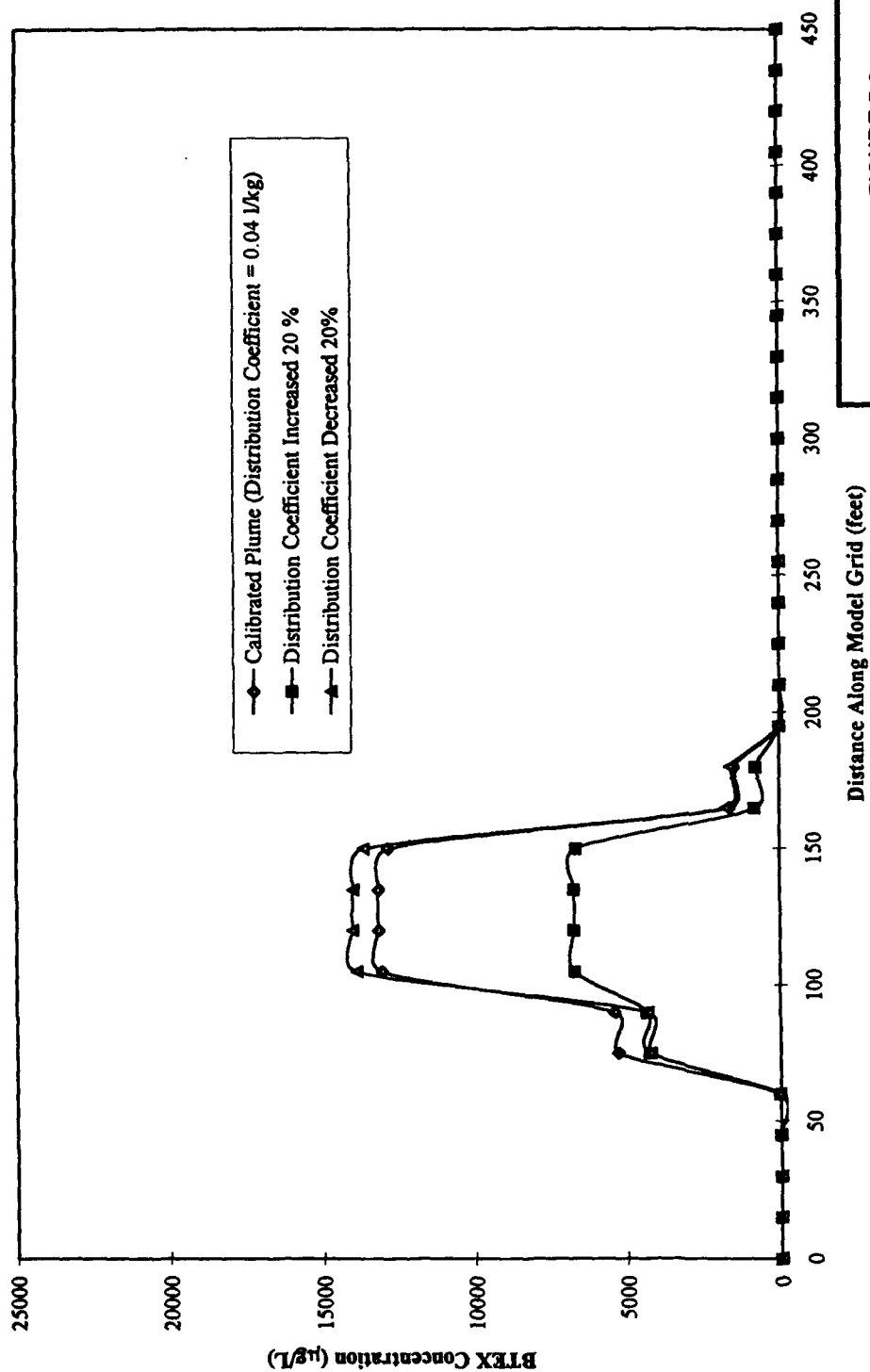


FIGURE 5.5

MODEL SENSITIVITY TO VARIATIONS IN ANAEROBIC DECAY COEFFICIENT

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Distance Along Model Grid (feet)

FIGURE 5.6

MODEL SENSITIVITY TO VARIATIONS IN THE DISTRIBUTION COEFFICIENT

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maximum BTEX concentration in the source area increased to 14,025 $\mu\text{g/L}$, without a noticeable change in the downgradient BTEX extent.

The effects of varying dispersivity are illustrated by Figure 5.7. Both longitudinal and transverse dispersivity were varied for this analysis, as the ratio of the two values was kept constant at 0.01. Increasing the dispersivity by 50 percent resulted in a very minor decrease in the maximum BTEX concentrations (by approximately 40 $\mu\text{g/L}$) without a noticeable change in downgradient extent. Decreasing the dispersivity by 50 percent produced a plume with slightly higher BTEX concentrations (by approximately 35 $\mu\text{g/L}$) without a noticeable change in downgradient extent. This model appears to be insensitive to dispersivity within the range of values evaluated for this analysis.

The effects of varying effective porosity are illustrated by Figure 5.8. Walton (1988) gives a range of 0.1 to 0.3 for the effective porosity of a silt. A comparison of the model using effective porosities that were increased and decreased by 25 percent (to 0.18 and 0.11, respectively) around the calibrated value of 0.15 shows a maximum BTEX concentration difference of approximately 4,500 $\mu\text{g/L}$ at the source and does not change the plume extent. Therefore, the modeled plume extent is relatively insensitive to the range of reasonable effective porosity values. However, within the source area the model is more sensitive to variations in porosity.

The results of the sensitivity analyses suggest that the calibrated model parameters used for this report are appropriate. The calibrated model is very sensitive to the transmissivity and the coefficient of anaerobic decay, and is relatively insensitive to the retardation coefficient, dispersivity, and effective porosity. Variations greater than 25 percent of the calibrated transmissivity value indicate that the model is unstable and mass balance errors result. Increasing the coefficient of anaerobic decay greatly diminishes the predicted maximum BTEX concentrations and only the coefficient of anaerobic decay results in an actual destruction of (or decrease in) the mass of BTEX. Lowering the transmissivity or the coefficient of anaerobic decay has a reverse effect, and maximum concentrations of BTEX in the aquifer are increased. The model appears relatively insensitive to the retardation factor and dispersivity; however, variation of values for these parameters contributed toward an appropriate plume configuration.

5.6 MODEL RESULTS

To predict fate and transport of dissolved BTEX compounds at Building 1212, three Bioplume II simulations (RNA, Biovent, and Excavate) were run under different sets of

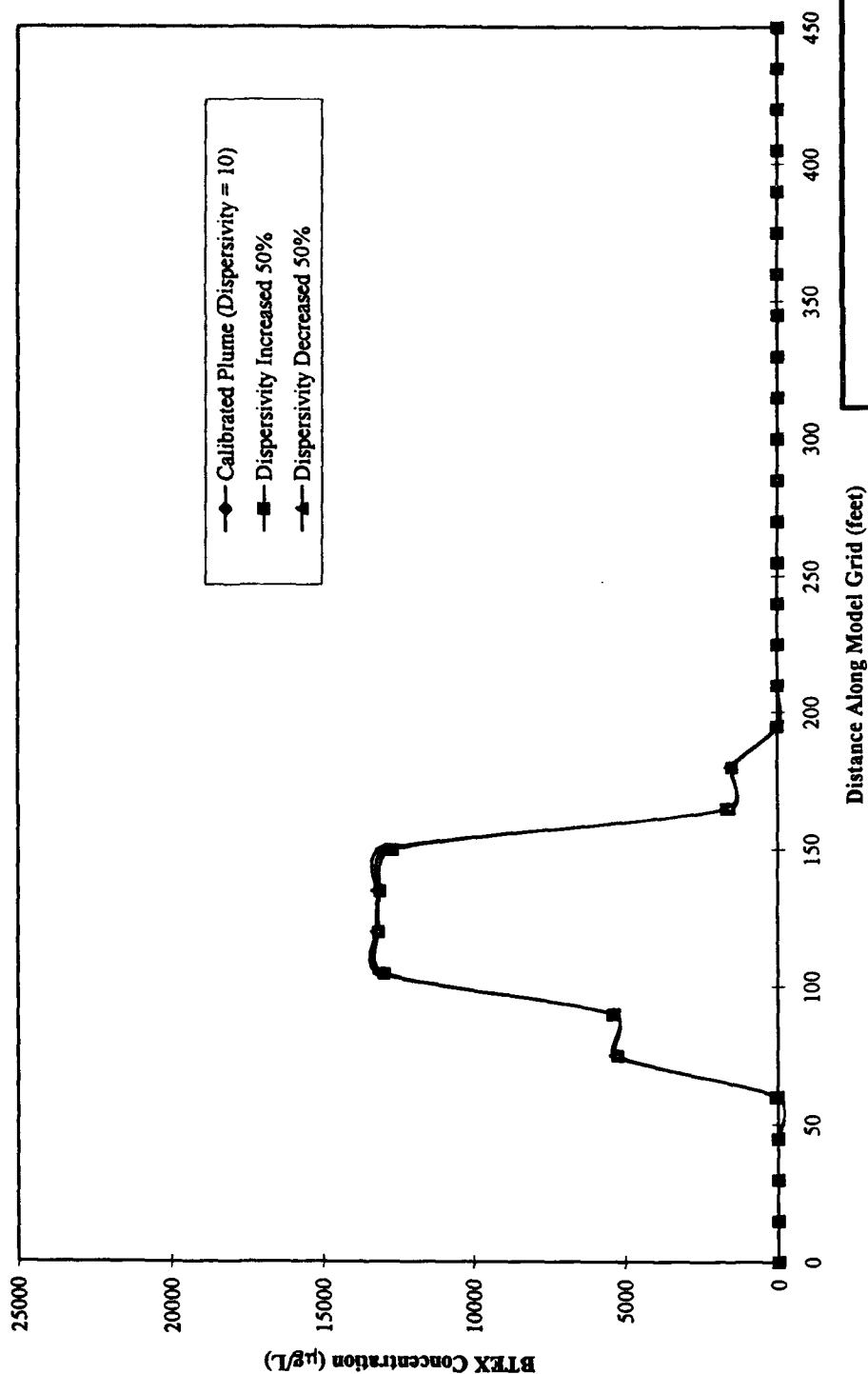


FIGURE 5.7

MODEL SENSITIVITY TO VARIATIONS IN DISPERSIVITY

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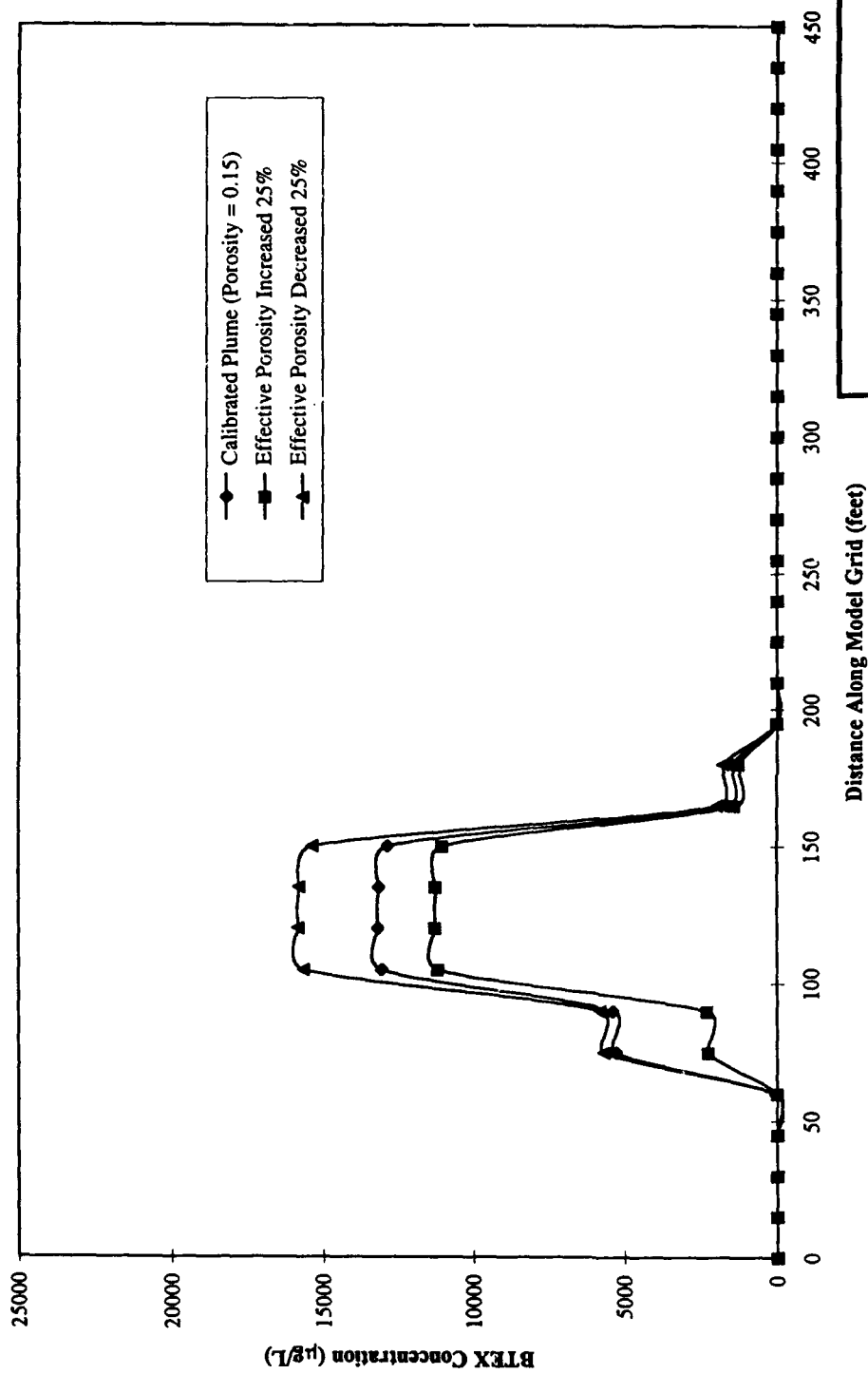


FIGURE 5.8

**MODEL SENSITIVITY TO
VARIATIONS IN EFFECTIVE POROSITY**

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Fairchild AFB, Washington

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conditions. The first simulation (RNA) assumed the physical weathering processes that currently operate to reduce residual BTEX in source area soils at the site will continue into the future. The second simulation (Biovent) assumed that through the implementation of a soil bioventing system, the soil source is reduced and results in an annual 50-percent decrease in BTEX entering the groundwater per year. The third simulation (Excavate) assumed that remaining contaminated soils at the site are excavated and replaced with clean backfill. The last two model scenarios assume that groundwater is remediated through natural attenuation processes. All three models assume that current contamination sources at the site will not increase because of the replacement or removal of faulty distribution systems and USTs in 1995 and 1996. Input and output files for each simulation are presented in Appendix D. Model results are described in the following sections.

Each model is evaluated with respect to maximum total BTEX concentrations and the extent of the 5- $\mu\text{g/L}$ total BTEX isopleth. The 5- $\mu\text{g/L}$ isopleth was selected on the basis of the Washington State groundwater maximum contaminant level (MCL) for benzene (5 $\mu\text{g/L}$). Because of Bioplume II limitations, the model simulations assume the total BTEX concentration is entirely benzene. Site data indicate that benzene is a relatively minor constituent in the dissolved BTEX fraction at Building 1212 (Table 4.3). Therefore, the selection of the 5- $\mu\text{g/L}$ isopleth likely overestimates the actual future benzene concentrations because current benzene concentrations are less than 17 percent of the total dissolved BTEX mass at the site.

5.6.1 Natural Source Weathering (Model RNA)

Model RNA was used to simulate the migration and biodegradation of the BTEX plume assuming that only natural physical weathering decreased BTEX loading in the source area. Physical weathering included dissolution of BTEX from residual contamination in saturated soils into groundwater and from BTEX dissolution into infiltrating precipitation that contacts residual contamination in the vadose zone. This model also assumes that the contaminant source is reduced slightly by volatilization of BTEX in the vadose zone or by chemical or biological degradation of residual product remaining in site soils.

In order to simulate the anticipated decrease in the source size and composition, model RNA utilizes 22 pumping periods. The first pumping period is a duplicate of the calibrated model conditions. Each of the following 20 pumping periods has a duration of

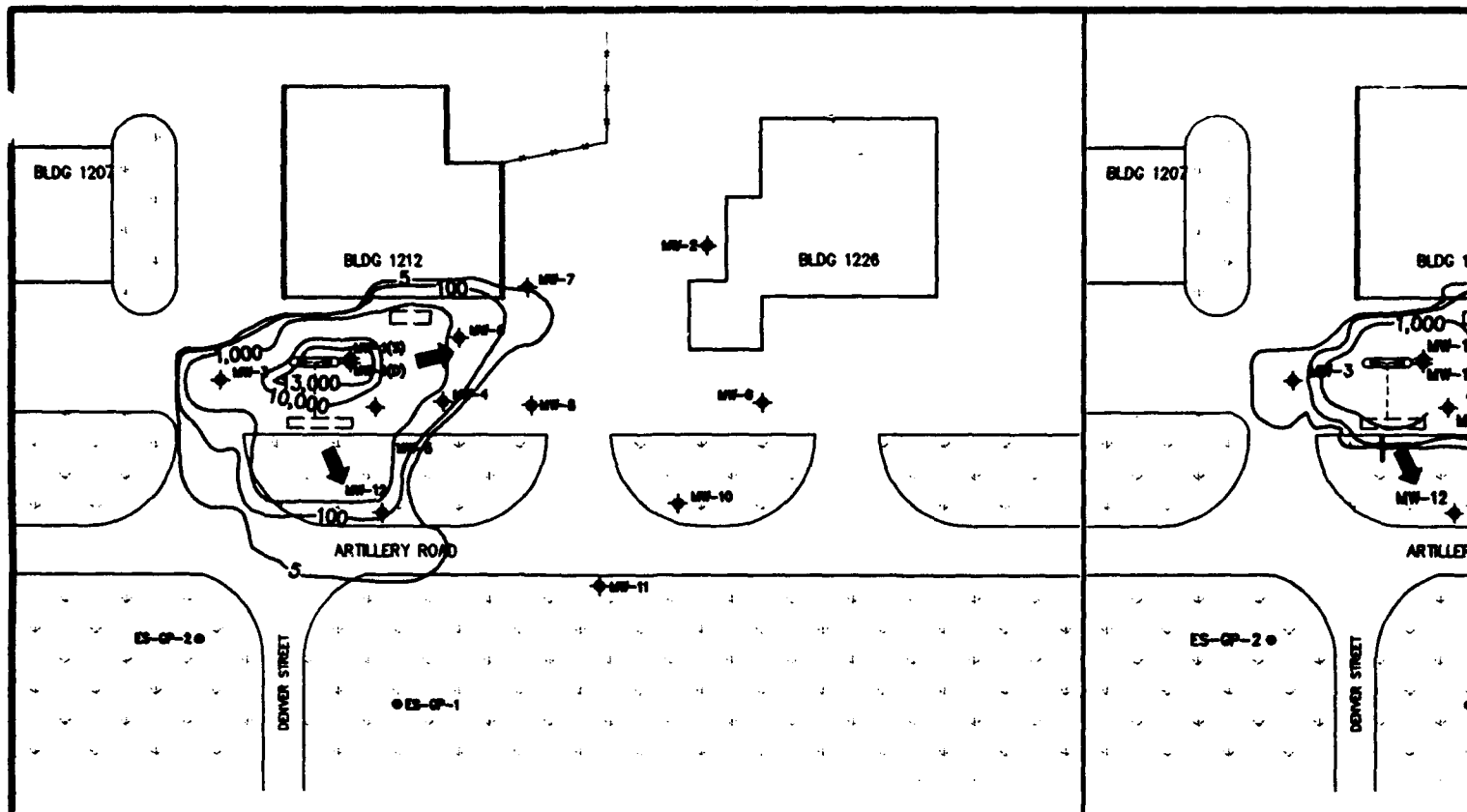
1 year and assumes a BTEX injection rate lower than the previous period as a result of weathering. The reduced BTEX injection rates represents a geometric source reduction rate of approximately 5 percent per year. The source reduction rate of 5 percent is potentially a conservative value for natural source weathering. The final pumping period assumes the source has been removed through weathering, and simulates the long-term fate and transport of the groundwater plume for an additional 15 years.

This model predicts decreasing maximum plume concentrations, with the plume extent receding from the calibrated position for the duration of the model simulation. Figure 5.9 shows the modeled plume for 2016 (20 years of simulated weathering), 2026 (30 years of simulated weathering), and 2030 (34 years of simulated weathering). After 20 years, the modeled downgradient extent of the 5- $\mu\text{g/L}$ BTEX isopleth recedes approximately 60 feet in the vicinity of MW-12 and approximately 20 feet in the vicinity of MW-7. The BTEX plume does not leave the site or impact any potential receptor exposure points during any of the model simulations. Within the source area, the extent of the 1,000-mg/L contour retreats approximately 20 feet toward the source area, and the maximum BTEX concentration decreases by 63 percent, from approximately 13,178 $\mu\text{g/L}$ to 4,915 $\mu\text{g/L}$. (Figure 5.9). After 30 years of weathering (year 2026), the 5- $\mu\text{g/L}$ isopleth recedes an additional 20 feet upgradient from the year 20 position in the vicinity of MW-7, and total BTEX concentrations decrease to a maximum of 1,731 $\mu\text{g/L}$ or 13 percent of the calibrated maximum concentration. After 34 years of natural weathering, the model suggests that the groundwater plume will have almost completely attenuated, with a maximum BTEX concentration of 13 $\mu\text{g/L}$ (Figure 5.9). Further model simulation suggests that after 34 years, the plume is completely degraded to below 5 $\mu\text{g/L}$.

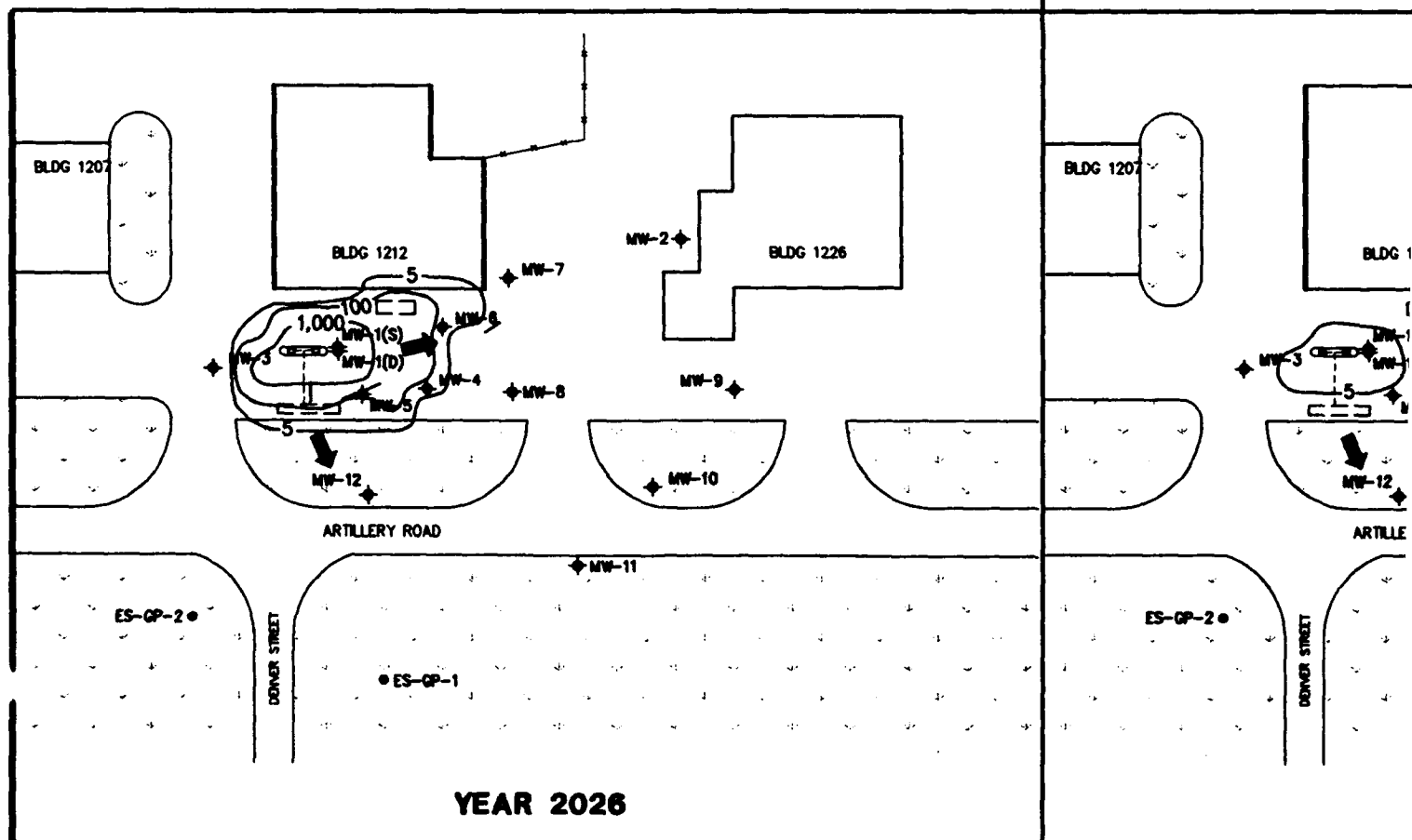
These results suggest that the maximum observed BTEX concentrations will steadily decrease over the next 34 years without any further engineered removal (i.e., assuming only physical weathering is taking place in source soils). Furthermore, the results suggest that the dissolved BTEX plume is steadily decreasing. Therefore, physical source weathering should be sufficient to reduce the dissolved BTEX concentrations and limit any future downgradient migration of the plume.

5.6.2 Engineered Source Reduction (Model Biovent)

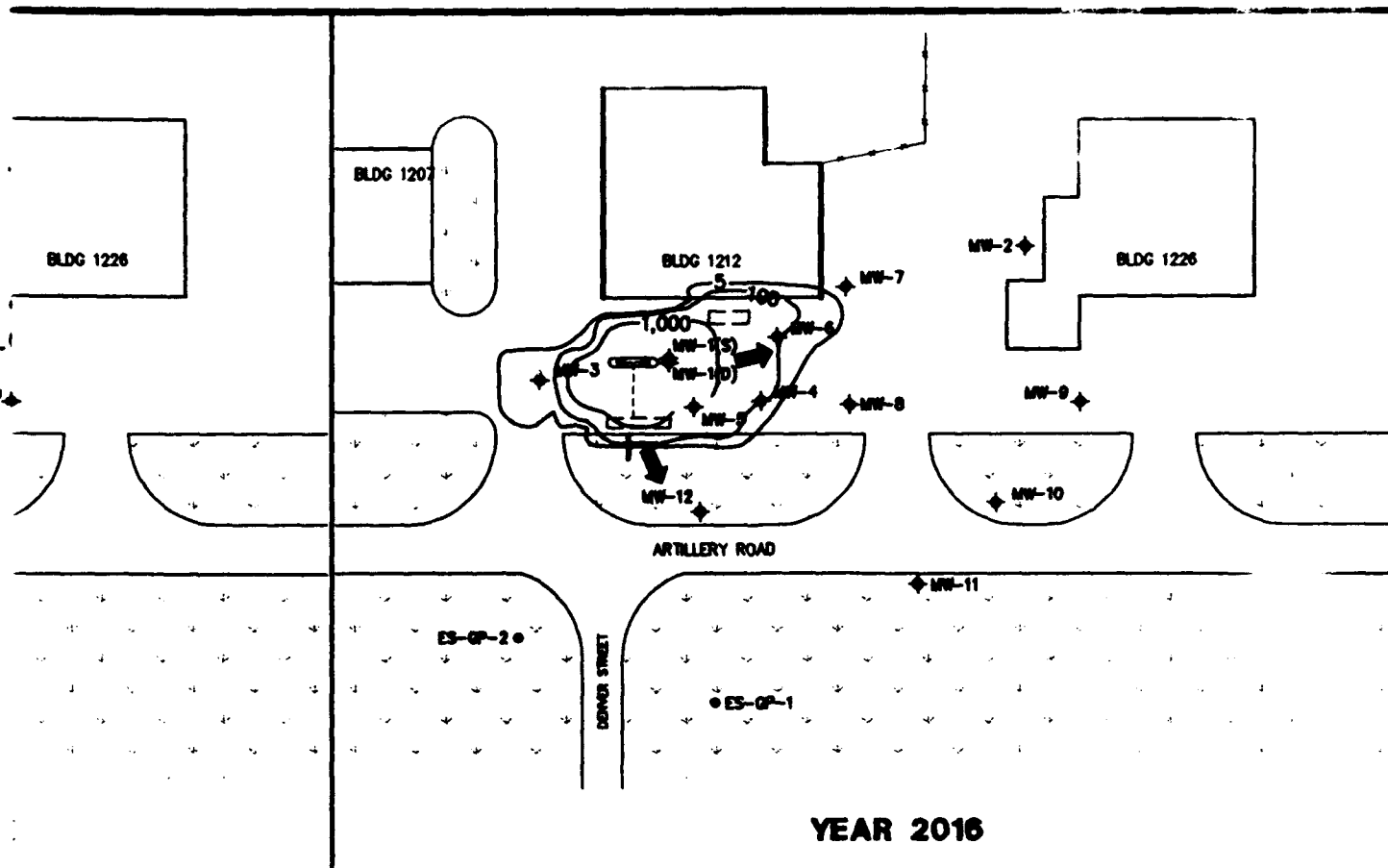
To illustrate the impact of engineered source reduction activities upon dissolved BTEX migration, model Biovent incorporates decreasing BTEX loading rates, under the assumption that a bioventing system will be used to remediate soil contamination in the



CALIBRATED BTEX PLUME



YEAR 2026

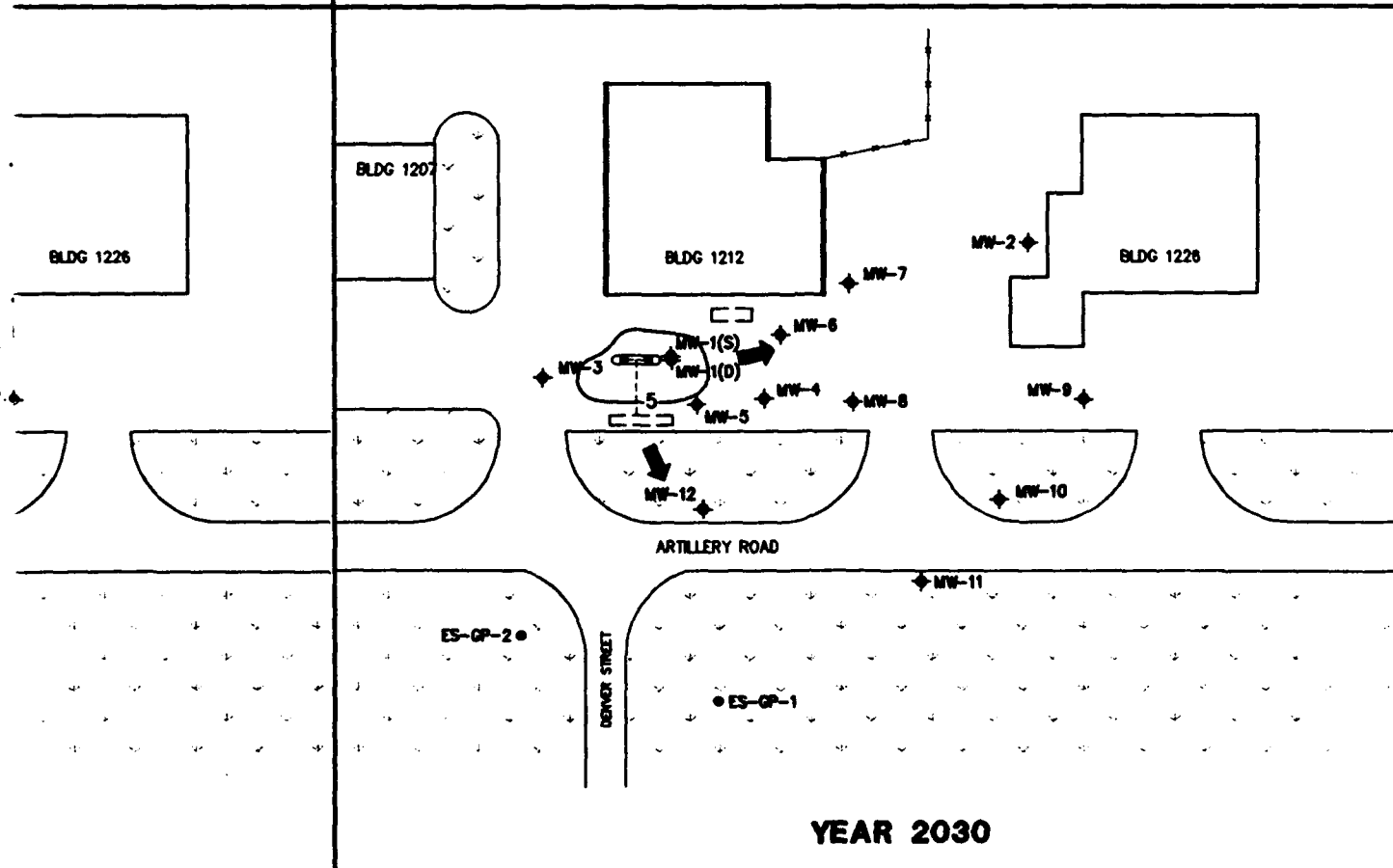


MW-2

ES-GP-1



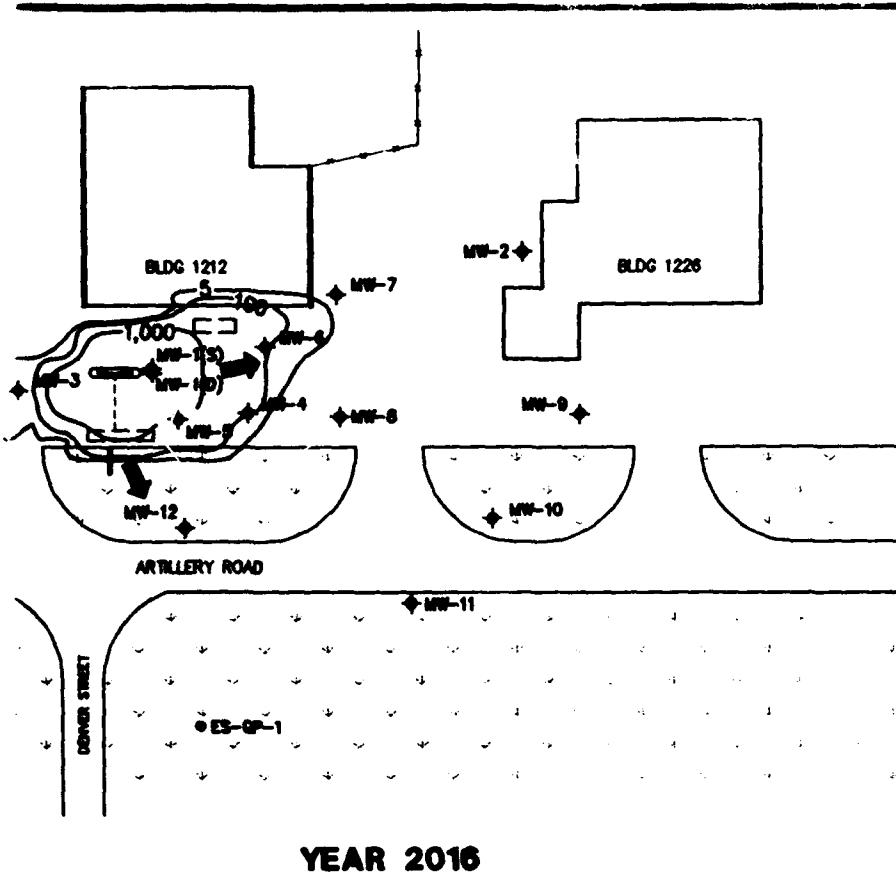
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- LEGEND**
- MW-2 ◆ MONITORING WELL
 - ES-GP-1 ● MONITORING POINT
 - GRASSY AREAS
 - ➔ APPROXIMATE GROUNDWATER FLOW DIRECTION
 - 5— LINE OF EQUAL BTEX CONCENTRATION ($\mu\text{g/L}$)

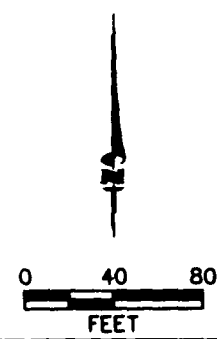
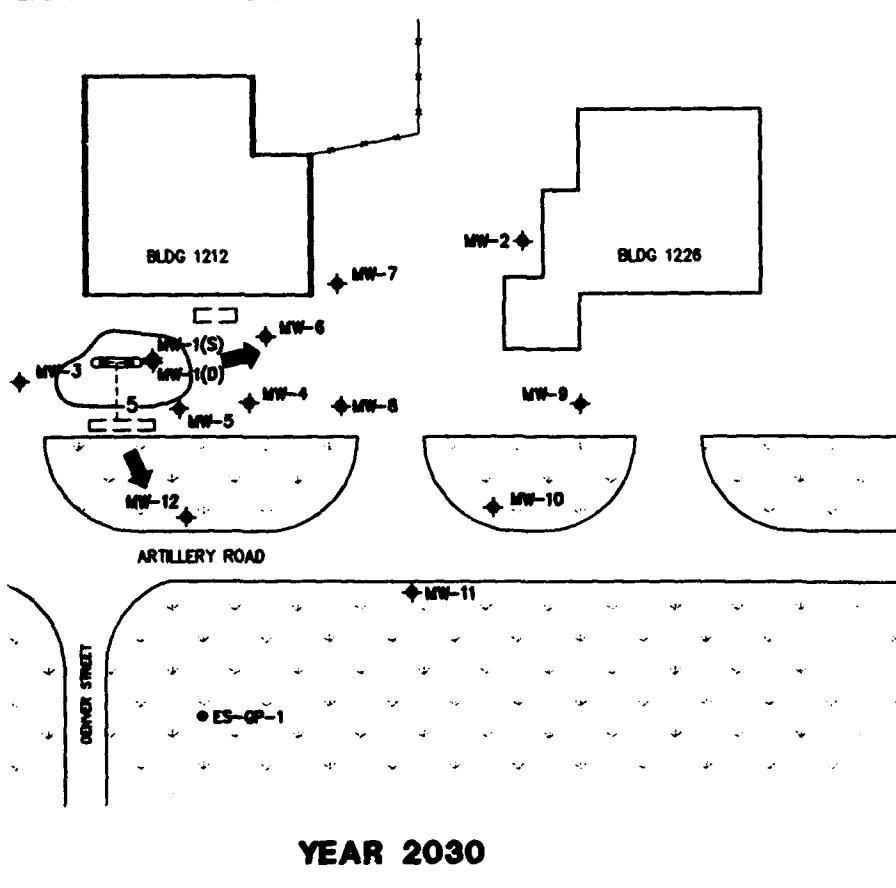


FIGURE 5.9

MODEL RNA

PREDICTED PLUME MIGRATION

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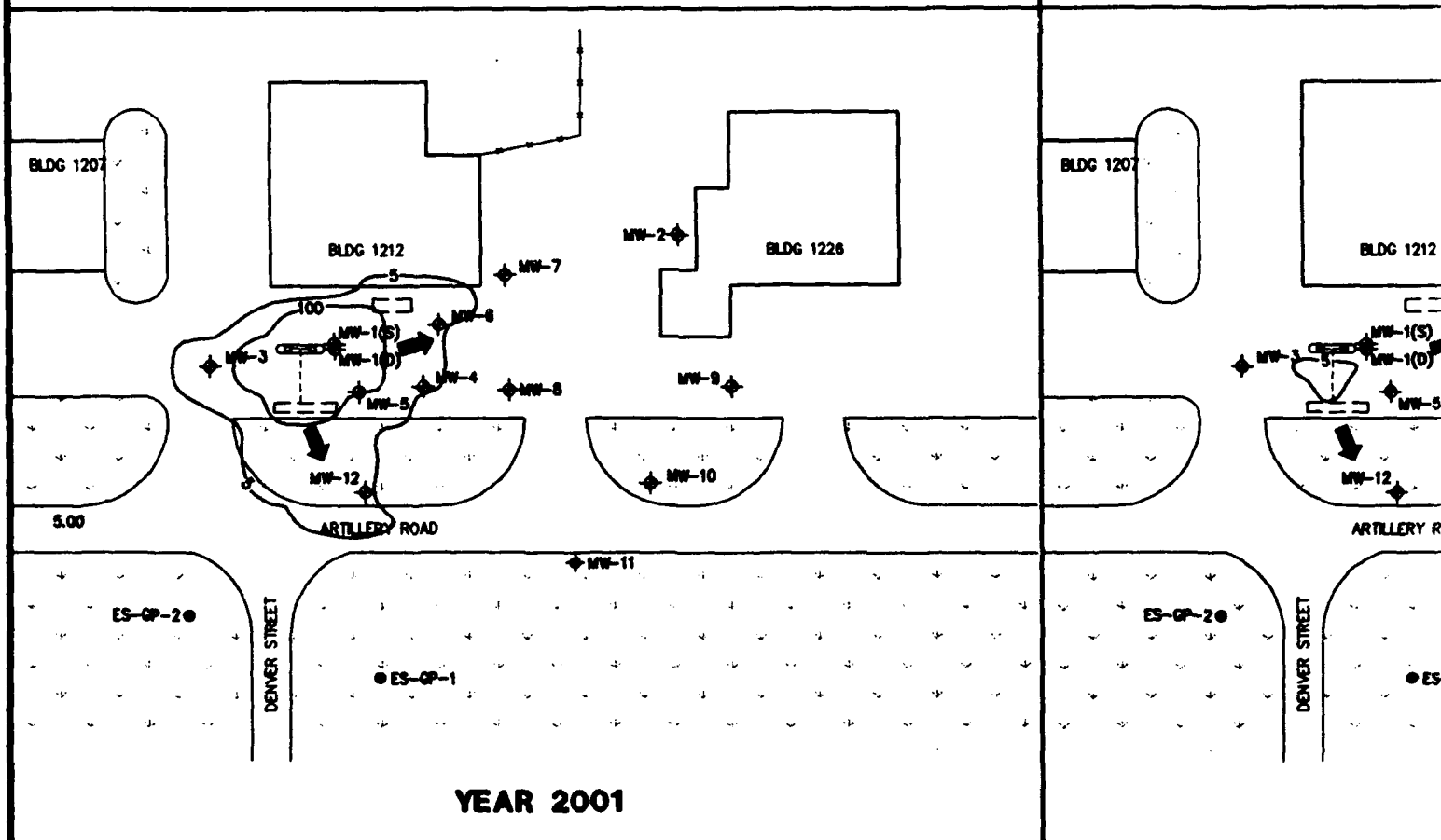
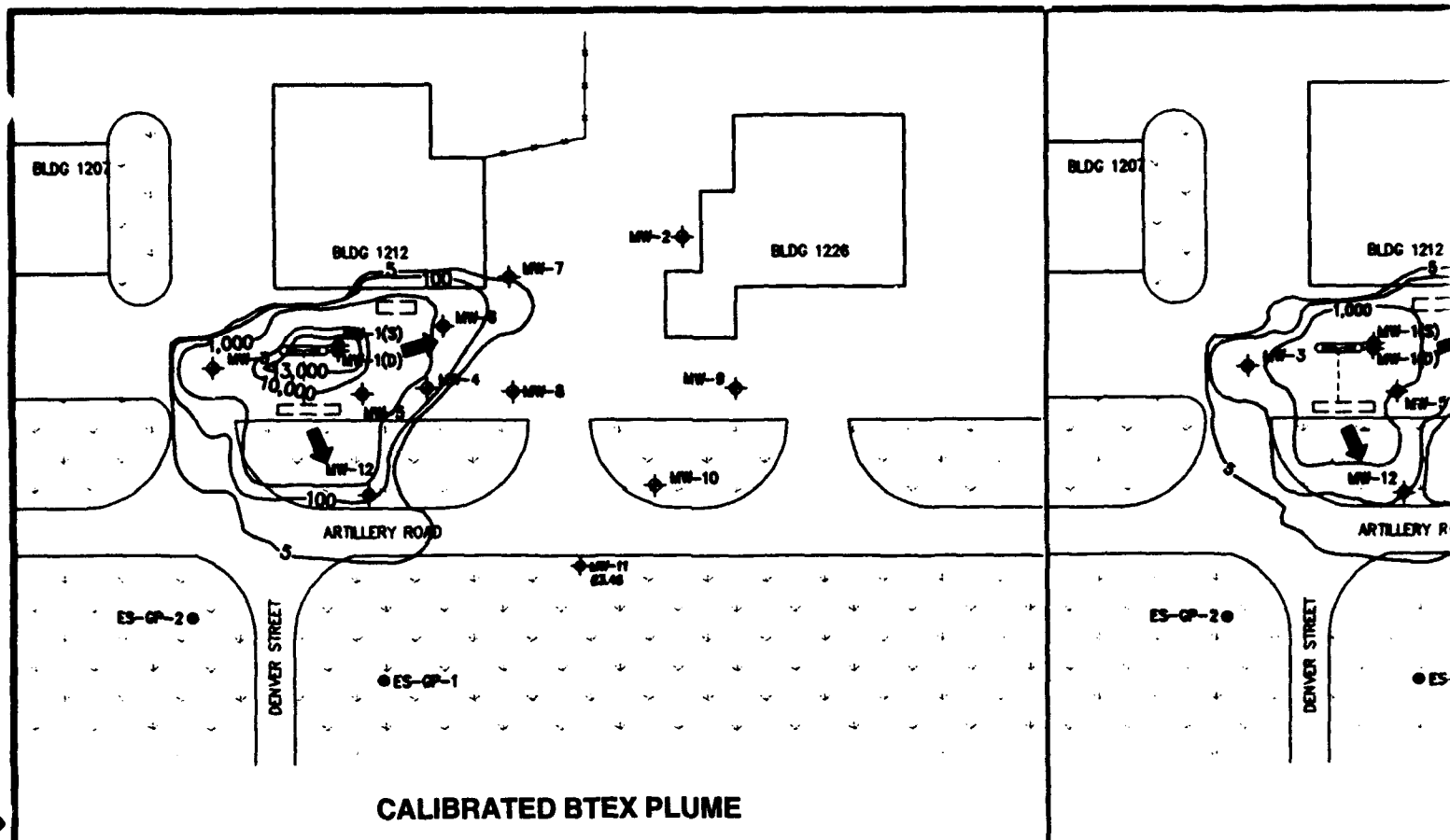
Denver, Colorado

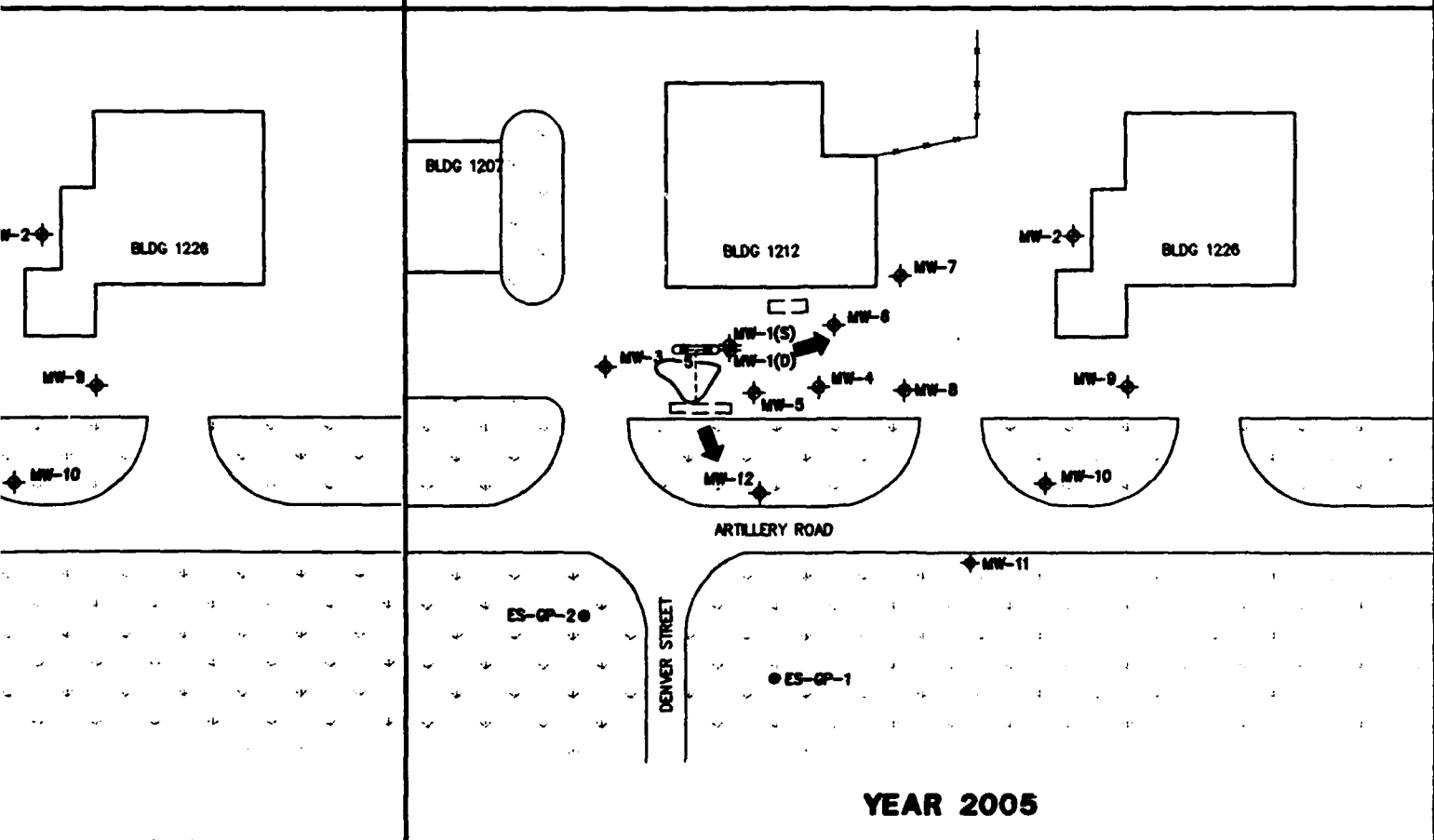
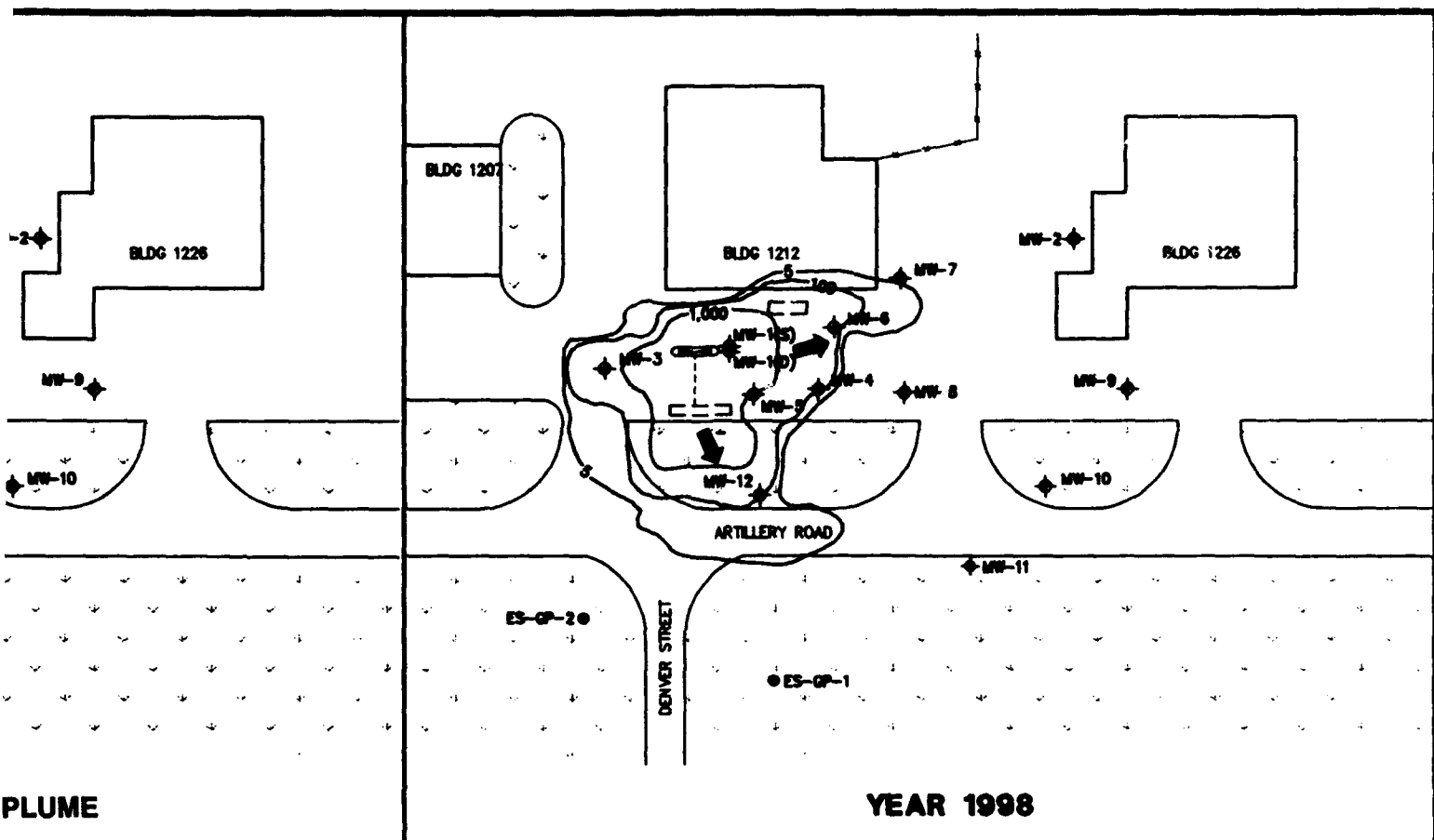
source areas. Bioventing is an *in situ* bioremediation process where low-flow air injection is used to enhance the biodegradation of organic contaminants in the subsurface vadose zone soil by supplying oxygen to indigenous microbes. Bioventing was simulated in the model through an annual 50-percent reduction in BTEX loading rates over a 5-year period.

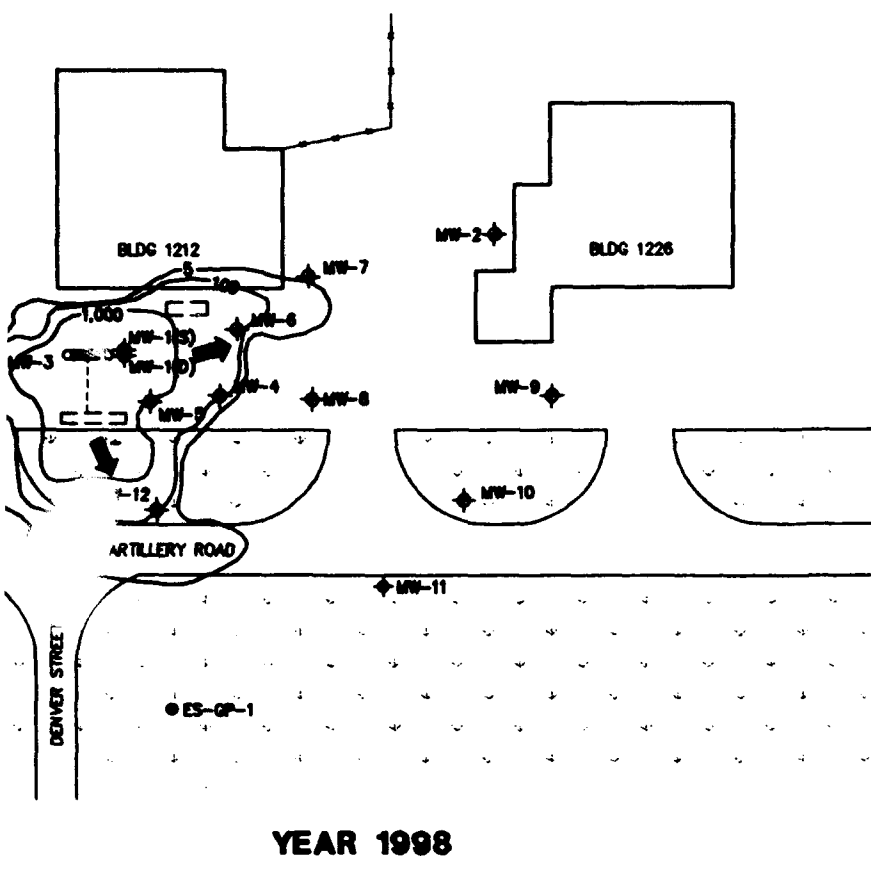
The Biovent model assumptions are conservative when compared to anticipated BTEX mass removal from soil bioventing. Implementation of bioventing soil remediation has been accompanied by reductions in soil BTEX concentrations averaging over 90 percent per year at a group of 16 other sites (AFCEE, 1994). Furthermore, soil sampling results collected during a bioventing pilot study at a nearby Fairchild AFB fuel spill site (Parsons ES, 1996) indicate that source reduction was greater than 50 percent. Therefore, assuming a 50-percent reduction in BTEX mass may underestimate the actual impact of a bioventing system on BTEX loading to site groundwater, and effectively lengthen the predicted remediation time.

Model Biovent was run with seven pumping periods. The first period is a duplicate of the calibrated model. The next five pumping periods each last one year and include BTEX loading rates that decrease geometrically at 50 percent per year. After these five periods less than 3 percent of the original source remains. The final pumping period is continued for an additional 10 years to simulate the long-term fate and transport of the plume. While it is difficult to quantify the actual decrease in the BTEX loading rates that could be brought about by bioventing, a model based on these assumptions can provide a useful indication of the potential effects of source reduction.

This model predicts a rapid decrease in source area BTEX concentrations followed by a slower decrease in the areal extent of the plume. Figure 5.10 presents model results for the years 1998 (2 years after implementation of bioventing), 2001 (5 years after implementation of bioventing), and 2005 (9 years after implementation of bioventing). Two years after implementation of bioventing, the maximum source-area BTEX concentration has decreased 60 percent, from approximately 13,178 $\mu\text{g/L}$ to 5,150 $\mu\text{g/L}$. However, the model predicts that the downgradient plume extent (as defined by the 5- $\mu\text{g/L}$ contour) will remain at the calibrated plume extent. The maximum predicted BTEX concentration in year 2001 is 94 percent less than the calibrated model. After 9 years of active and passive remediation, the plume is confined to the source area, and the maximum simulated BTEX concentration (5.7 $\mu\text{g/L}$) lies within the source area. The model predicts that the maximum BTEX concentration will be less than 5 $\mu\text{g/L}$ 10 years after the start of bioventing activities.







LEGEND

- MW-2 ◆ MONITORING WELL
- ES-GP-1 ● MONITORING POINT
- GRASSY AREAS
- ➔ APPROXIMATE GROUNDWATER FLOW DIRECTION
- 5— LINE OF EQUAL BTEX CONCENTRATION ($\mu\text{g/L}$)

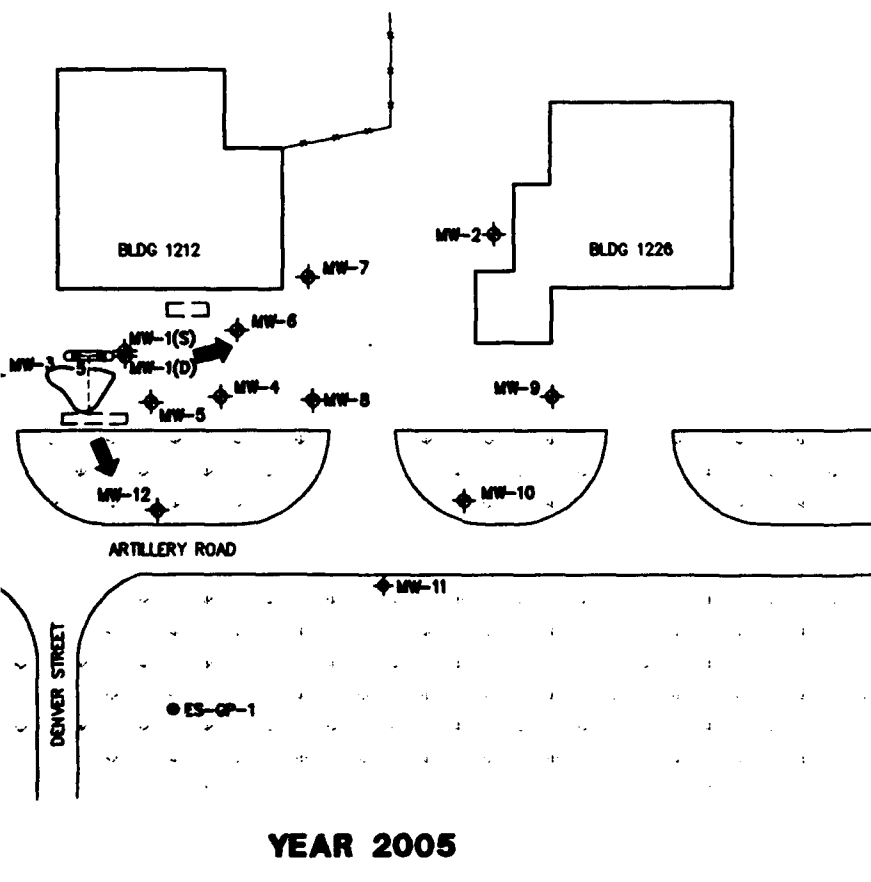


FIGURE 5.10

MODEL BIOVENT PREDICTED PLUME MIGRATION

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Fairchild AFB, Washington

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5.6.3 Contaminated Soil Excavation (Model Excavate)

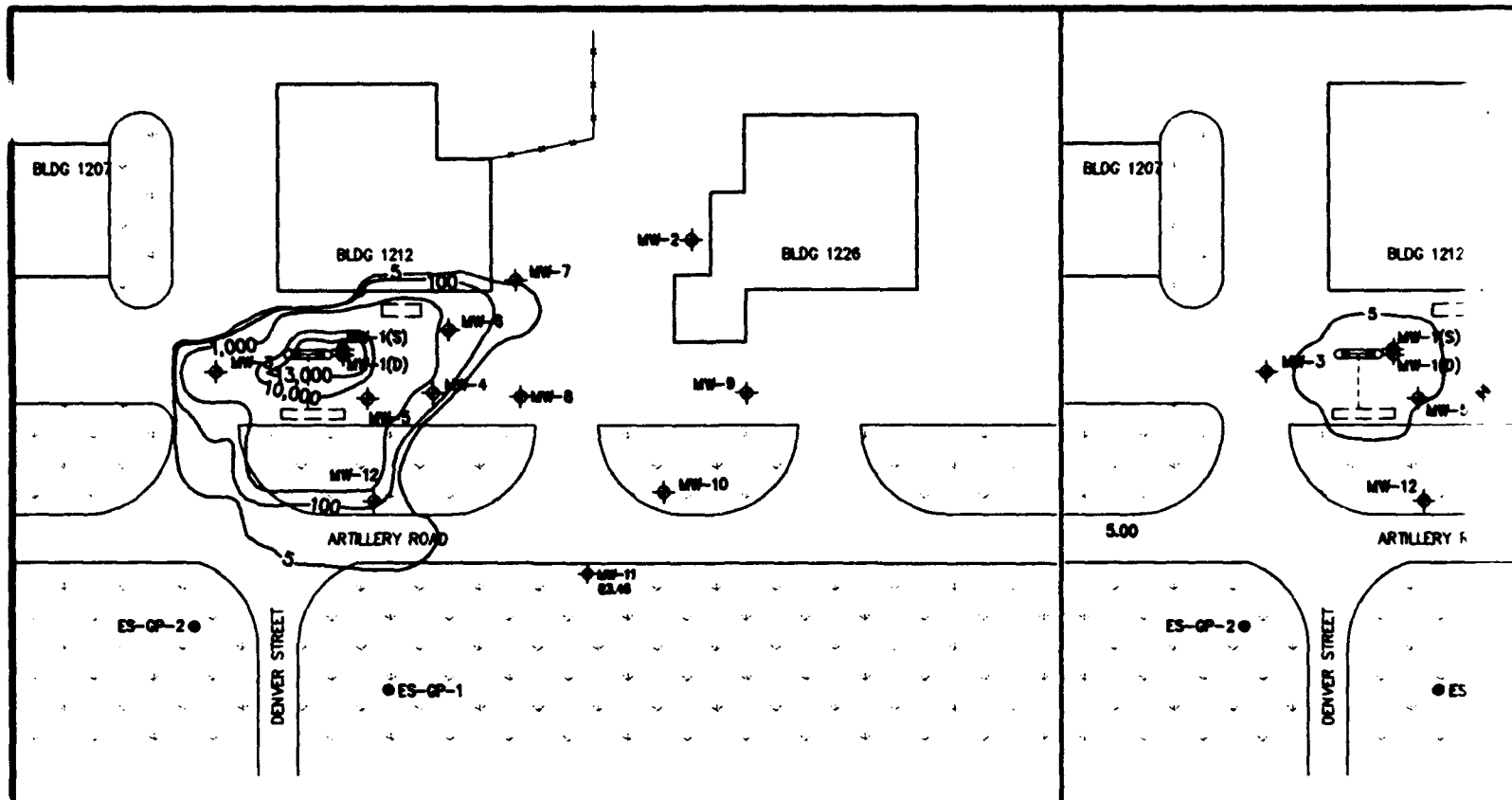
Model Excavate was run to illustrate the scenario of complete source removal using soil excavation at Building 1212. Contaminated source soil excavation is the least conservative of the three scenarios modeled for this site. This model was run with only two pumping periods. As in the two previous models, the first pumping period is a copy of the calibrated model. The final pumping period simulates the removal of the source and the BTEX source loading is eliminated. The pumping period continues to simulate the long-term fate and transport of the plume using RNA to remediate groundwater until the dissolved BTEX contamination has been reduced below 5 µg/L.

This model predicts a slightly faster decrease in maximum groundwater BTEX concentrations in the source area over a 6-year period. Figure 5.11 presents model predictions for 1, 5, and 6 years of remediation. Simulated maximum BTEX concentrations for this model decrease approximately 68 percent in the first year, from 13,178 µg/L to 4,225 µg/L. The downgradient plume extent remains unchanged from the calibrated position. The 5-year simulation (year 2001) predicts source-area BTEX concentrations will decrease by more than 99 percent, to a maximum predicted BTEX concentration of 34 µg/L. At this time, the model predicts the plume will be confined to the source area. At year 6 (2002) the model suggests that the plume will further recede within the source area, with a maximum BTEX concentration of 10 µg/L. After year 6, total BTEX levels fall below 5 µg/L.

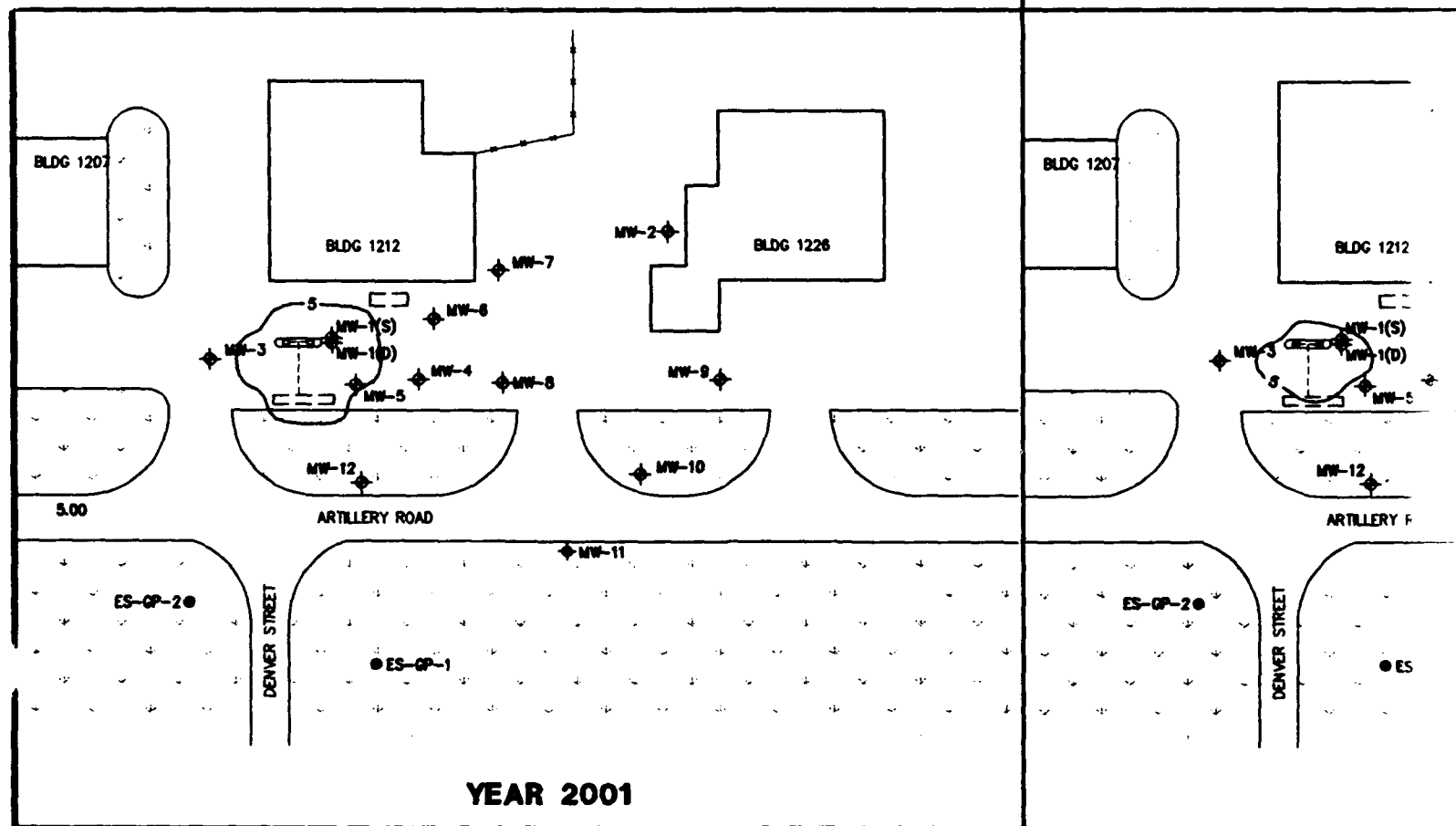
5.7 CONCLUSIONS AND DISCUSSION

Three model scenarios were used to predict BTEX attenuation and migration rates at Building 1212. The first scenario, model RNA, assumed natural physical weathering of the residual soil source contamination. The second scenario, model Biovent, assumed that as a result of the operation of a bioventing system, dissolved BTEX would be completely eliminated in 5 years. Model Excavate assumes removal of the BTEX source in soils through excavation of contaminated soils and the use of RNA to treat dissolved BTEX in groundwater. The results of all three Bioplume II model scenarios suggest that dissolved BTEX plume will steadily shrink and will not advance beyond the current plume front.

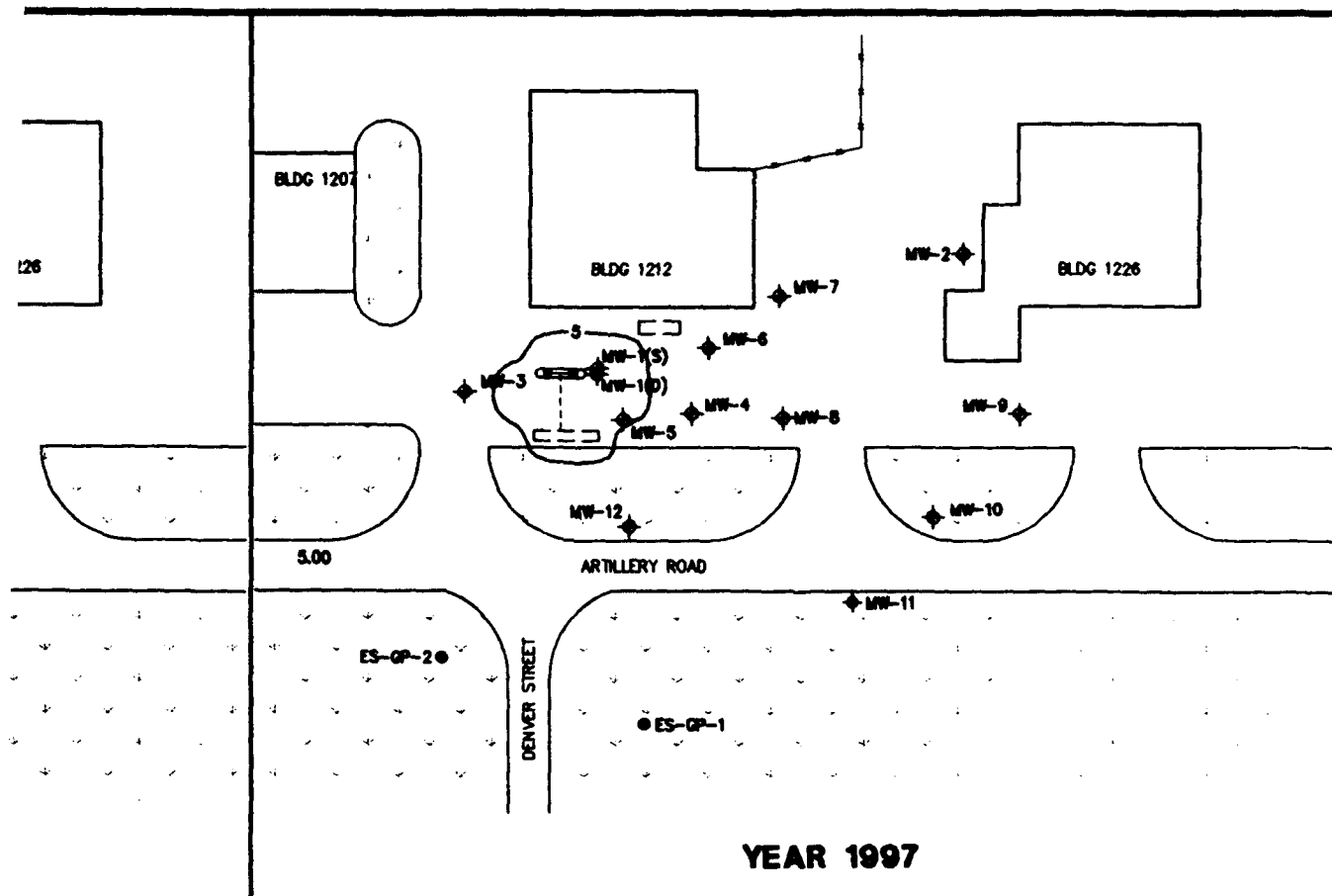
Model RNA results suggest that the BTEX plume will be completely degraded by natural weathering processes after approximately 34 years. By assisting RNA through bioventing and excavation, models Biovent and Excavate predict that complete



CALIBRATED BTEX PLUME



YEAR 2001



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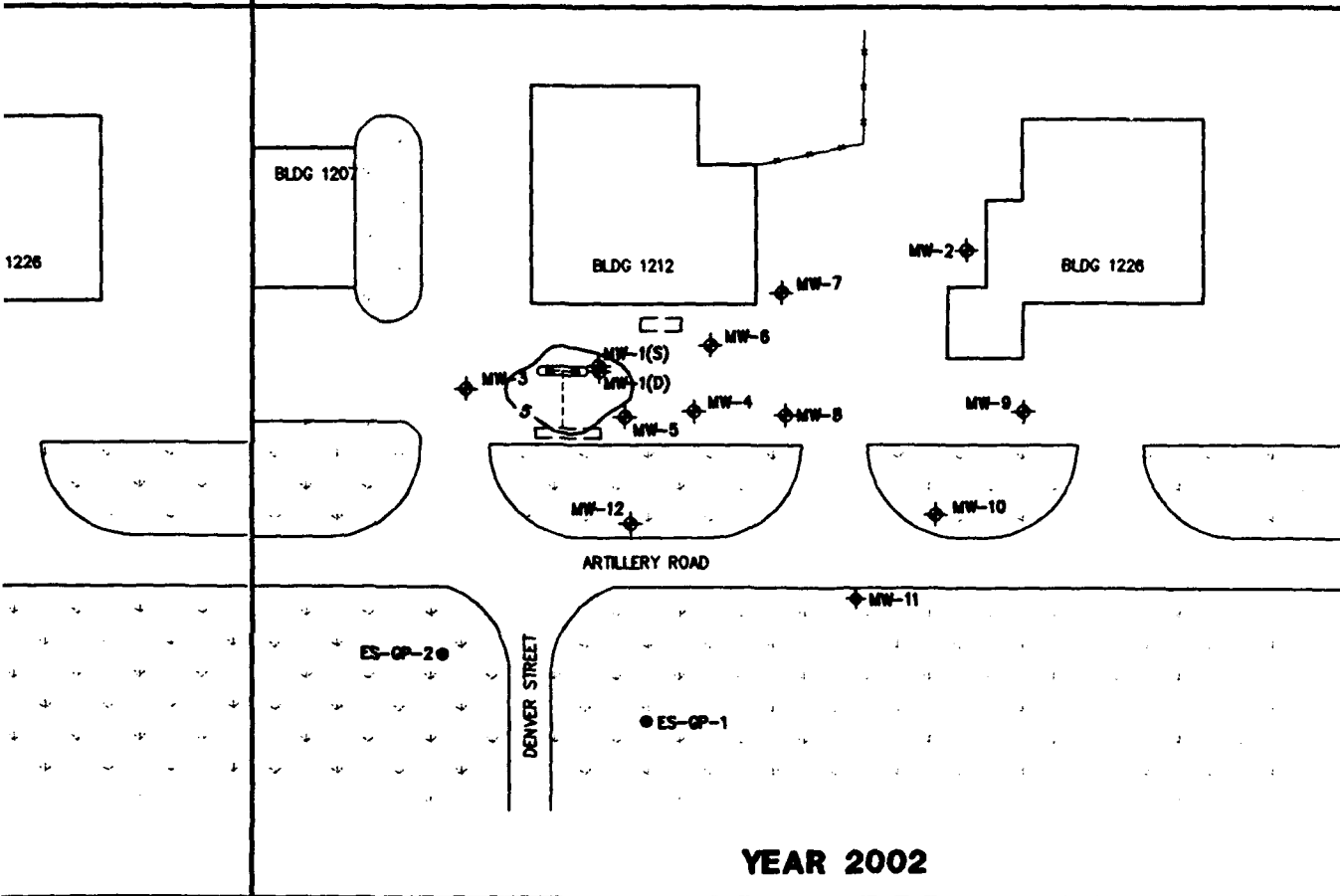
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ES-GP-1 ● MON

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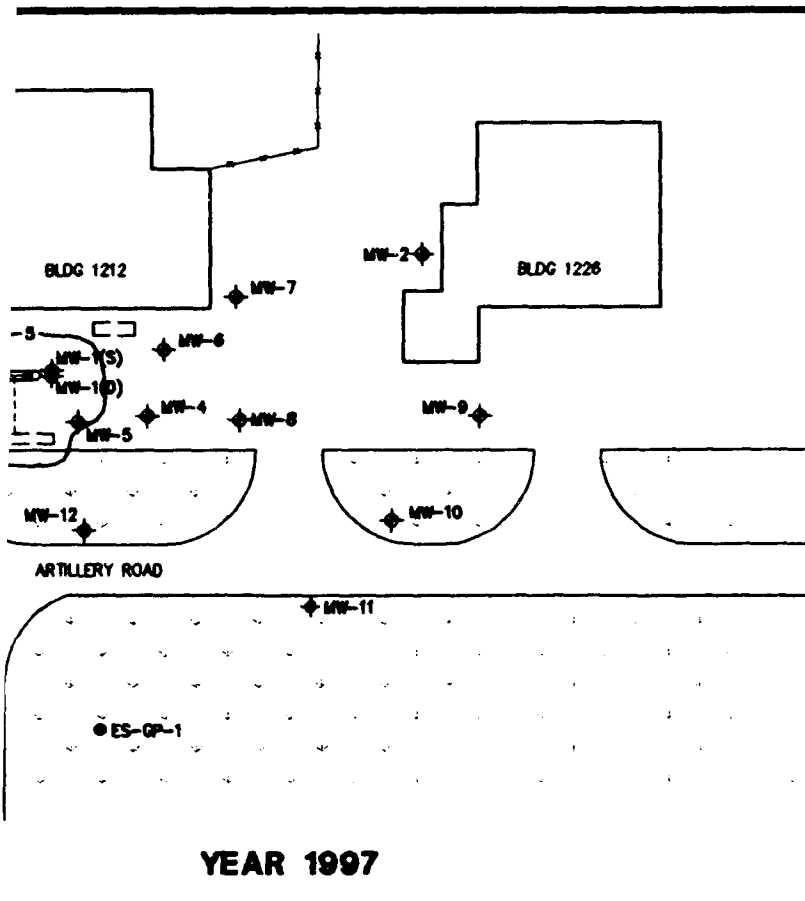


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- MW-2 ◆ MONITORING WELL
- ES-GP-1 ● MONITORING POINT
- GRASSY AREAS
- ➔ APPROXIMATE GROUNDWATER FLOW DIRECTION
- 5- LINE OF EQUAL BTEX CONCENTRATION ($\mu\text{g/L}$)

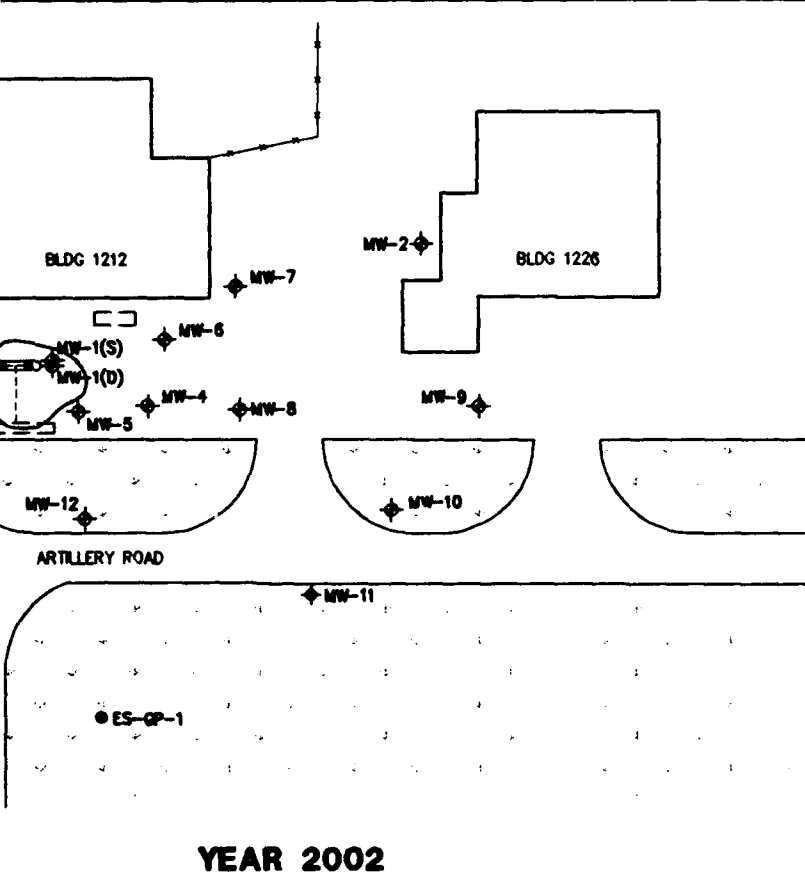


FIGURE 5.11

MODEL EXCAVATE PREDICTED PLUME MIGRATION

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remediation of the dissolved BTEX plume will require approximately 9 and 6 years, respectively. All three models predict that the leading edge of the plume will not advance beyond the calibrated position as RNA of dissolved groundwater BTEX concentrations proceeds.

In all simulations, several conservative assumptions are built into the model. The use of these conservative model assumptions suggests that natural attenuation of BTEX contamination at the site may exceed model predictions. Several of the conservative model assumptions are described below:

- 1) Aerobic respiration, iron reduction, sulfate reduction, and methanogenesis all are occurring at this site. Aerobic processes are effectively simulated within the anaerobic core of the plume where they potentially account for less than 23 percent of degradation. At the leading edge of the plume, however, the aerobic contribution is more significant and is very likely underestimated by a first order biodegradation rate. In addition, aerobic biodegradation may potentially become more important within the core of the plume as residual BTEX source concentrations are removed, thereby allowing more oxygenated rainwater to percolate through vadose zone soils.
- 2) The stoichiometry used to determine the ratio between electron acceptors and total BTEX assumed that no microbial cell mass was produced during the reactions. As discussed in Section 4.3.2, this approach may be too conservative by a factor of three.
- 3) Dissolved oxygen was introduced only with groundwater recharge at the upgradient model boundary and within the groundwater recharge cells; however, aerobic groundwater recharge likely occurs across much of the site as a result of precipitation.
- 4) A low coefficient of retardation for benzene (1.43) was used for all the BTEX compounds in the model simulations. Minimum retardation coefficient values for the other BTEX compounds range from 2.05 to 3.57. The use of a conservative retardation coefficient tends to increase the velocity of contaminant migration, but may provide a more accurate estimate of benzene transport. However, realistic retardation coefficients for toluene, ethylbenzene, and xylenes are higher than that for benzene, which will slow the actual migration of these compounds, thereby increasing their susceptibility to biodegradation.

- 5) The calibrated decay constant of 0.007 day^{-1} is conservative when compared to estimated site values and literature values of 0.001 day^{-1} to 0.185 day^{-1} (see Section 5.3.5.3). The use of a low decay constant increases the travel distance of the contaminant plume, as well as the time required for natural attenuation.
- 6) Calibrated source concentrations in the models were higher than observed concentrations. This introduction of extra contaminant mass likely results in the predictions being conservative because additional BTEX mass must be biodegraded to produce the observed results.

The three model simulations were run in order to account for uncertainties associated with the assumptions of future site conditions. The patterns of degradation of the plumes shown in models RNA, Biovent, and Excavate are feasible, given the observed BTEX concentrations, the conservative assumptions made in constructing the simulations, and the strong evidence of biodegradation. Model RNA is a "worst-case" scenario in that it assumes BTEX dissolution into the aquifer will continue while the source is being naturally weathered. Without engineered source reduction, dissolved BTEX contamination in that model remains for 34 years. Models Biovent and Excavate are more optimistic predictions which assume active source reduction will rapidly reduce the BTEX in site soils and therefore reduce any further dissolution into the groundwater. This results in more rapid attenuation of the dissolved BTEX plume.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of three groundwater remedial alternatives for contaminated groundwater at Building 1212. The intent of this evaluation is to determine if RNA of groundwater is an appropriate and cost-effective remedial approach to consider when developing final remedial strategies for the study area, especially when combined with other remedial technologies.

Section 6.1 presents the criteria used to evaluate groundwater remedial alternatives. Section 6.2 discusses the development of remedial alternatives considered as part of this demonstration project. Section 6.3 provides a brief description of each of these remedial alternatives. Section 6.4 provides a more detailed analysis of the remedial alternatives using the defined remedial alternative evaluation criteria. The results of this evaluation process are summarized in Section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for shallow groundwater contamination at the site were evaluated based on (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion. This report focuses on the potential use of RNA and source reduction technologies to reduce dissolved BTEX concentrations in the shallow groundwater below Washington State regulatory action levels.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial technology or remedial alternative (which can be a combination of remedial approaches such as RNA and institutional controls) was analyzed to determine how effectively it will minimize groundwater plume expansion so that groundwater and surface water quality standards can be achieved at a downgradient POC. The expected

technical effectiveness based on case histories from other sites with similar conditions also is evaluated. The ability to minimize potential impacts on surrounding facilities and operations is considered. Also, the ability of each remedial alternative to protect both current and potential future receptors from potential risks associated with potentially completed exposure pathways is qualitatively assessed. This evaluation criterion also included permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and time until protection is achieved are described. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, also is evaluated.

6.1.2 Implementability

The technical implementation of each remedial technology or remedial alternative was evaluated in terms of technical feasibility and availability. Potential shortcomings and difficulties in construction, operations, and monitoring are presented and weighed against perceived benefits. Requirements for any post-implementation site controls such as LTM and land use restrictions are described. Details on administrative feasibility in terms of the likelihood of public acceptance and the ability to obtain necessary approvals are discussed.

6.1.3 Cost

The total cost (adjusted to present worth) of each remedial alternative was estimated for relative comparison. An estimate of capital costs, and operating and post-implementation costs for site monitoring and controls is included. An annual adjustment factor of 7 percent was assumed in present worth calculations. The annual adjustment factor is the difference between the rate of inflation and the cost of money (USEPA, 1993).

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing shallow groundwater contamination at the site. Factors considered included the objectives of the AFCEE natural attenuation demonstration program; contaminant, groundwater, and soil properties; current and future land uses; and

potential receptors and exposure pathways. The following section briefly describes each of these factors and how they were used to narrow the list of potentially applicable remedial technologies to the final remedial alternatives considered for the study area.

6.2.1 Program Objectives

The intent of the RNA demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting natural subsurface attenuation processes that can be factored into overall site remediation plans. The objective of this program and the specific demonstration at Fairchild AFB is to provide solid evidence of RNA of dissolved fuel hydrocarbons so that this information can be used to develop an effective groundwater remediation strategy. A secondary goal of this multi-site initiative is to provide a series of regional case studies that demonstrate that natural processes of contaminant degradation can often reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential receptor exposure pathways.

Because the objective of this program is to study natural processes in the saturated zone rather than all contaminated media (e.g., soil, soil gas, etc.), technologies have been evaluated based primarily on their potential impact on shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater also have been evaluated. Many of the source removal technologies evaluated in this section also will reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are not intended to remediate all contaminated media. Additional program objectives set forth by AFCEE include cost effectiveness and minimization of waste. Technologies that may best meet these AFCEE criteria include institutional controls, soil vapor extraction, bioventing, bioslurping, passive drain collection, biosparging, and RNA. Although alternatives involving soil excavation do not typically meet program objectives for cost effectiveness and waste minimization, excavation is considered a candidate remedial technology at this site because of a relatively low volume of soil requiring excavation and the future abandonment and removal of the fuel system. Under this program, slurry walls, sheet piling, carbon adsorption, and groundwater extraction with *ex situ* biological or chemical treatment of groundwater are not considered attractive technologies.

6.2.2 Contaminant Properties

The site-related contaminants considered as part of this demonstration in the study area are the BTEX compounds. The primary source of contamination at Building 1212 is the release into the site soils of fuel hydrocarbons from leaky USTs and the associated distribution lines. The recent excavation of the two 3,000-gallon gasoline tanks south of the fuel dispensers (Budinger and Associates, 1995) removed approximately 40 cubic yards of contaminated soil. However, not all contaminated soil was excavated. Though future fuel releases are not expected, contaminated soil remains as a source of contamination present at Building 1212. The physiochemical characteristics of gasoline and the individual BTEX compounds will greatly influence the effectiveness and selection of a remedial technology.

Gasoline is classified as an LNAPL with a liquid density of approximately 0.73 g/cc at 20°C [Biomedical and Environmental Information Analysis (BEIA), 1989]. Because gasoline is less dense than water, the LNAPL may become concentrated in the capillary fringe. Some of the individual gasoline constituents sorb very well to the soil matrix, others dissolve quickly into percolating groundwater, and yet others may volatilize into soil vapor. This "weathering" process results in a variable distribution of individual gasoline components in the soil, soil atmosphere, and groundwater with time and distance from the release (BEIA, 1989). Constituents in gasoline range from slightly to highly soluble in water. Overall solubility is approximately 300 mg/L. Gasoline also can act as a primary substrate for biological metabolism. Simultaneous biodegradation of aliphatic, aromatic, and alicyclic hydrocarbons has been observed. In fact, mineralization rates of hydrocarbons in mixtures, such as gasoline, may be faster than mineralization of the individual constituents as a result of cometabolic pathways (Jamison *et al.*, 1975; Perry, 1984).

The BTEX compounds are generally volatile, highly soluble in water, and adsorb less strongly to soil than other hydrocarbons in a petroleum mixture. These characteristics allow the BTEX compounds to leach more rapidly from contaminated soil into groundwater, and to migrate as dissolved contamination (Lyman *et al.*, 1992). All of the BTEX compounds are highly susceptible to *in situ* degradation by both biotic and abiotic mechanisms.

Benzene is very volatile, with a vapor pressure of 76 millimeters of mercury (mm Hg) at 20°C and a Henry's Law Constant of approximately 0.0054 atmosphere-cubic meters

per mole ($\text{atm}\cdot\text{m}^3/\text{mol}$) at 25°C (Hine and Mookerjee, 1975; Jury *et al.*, 1984). The solubility of pure benzene in water at 20°C has been reported to be 1,780 mg/L (Verschueren, 1983). Benzene is normally biodegraded to carbon dioxide, with catechol as a short-lived intermediate (Hopper, 1978; Ribbons and Eaton, 1992).

Toluene is also volatile, with a vapor pressure of 22 mm Hg at 20°C and a Henry's Law Constant of about $0.0067 \text{ atm}\cdot\text{m}^3/\text{mol}$ at 25°C (Pankow and Rosen, 1988; Hine and Mookerjee, 1975). Toluene sorbs more readily to soil media relative to benzene, but still is very mobile. The solubility of pure toluene in water at 20°C is approximately 515 mg/L at 20°C (Verschueren, 1983). Toluene has been shown to degrade to pyruvate, caetaldehyde, and completely to carbon dioxide via the intermediate catechol (Hopper, 1978; Wilson *et al.*, 1986; Ribbons and Eaton, 1992).

Ethylbenzene has a vapor pressure of 7 mm Hg at 20°C and a Henry's Law Constant of $0.0066 \text{ atm}\cdot\text{m}^3/\text{mol}$ (Pankow and Rosen, 1988; Valsaraj, 1988). Ethylbenzene sorbs more strongly to soils than benzene and toluene (Kenaga and Goring, 1980; Means *et al.*, 1980; Hassett *et al.*, 1983; Fetter, 1993). Pure ethylbenzene is also less soluble than benzene and toluene in water at 152 mg/L at 20°C (Verschueren, 1983; Miller *et al.*, 1985). Ethylbenzene ultimately degrades to carbon dioxide via its intermediate 3-ethylcatechol (Hopper, 1978; Ribbons and Eaton, 1992).

The three isomers of xylene have vapor pressures ranging from 7 to 9 mm Hg at 20°C and Henry's Law Constants of between 0.005 and $0.007 \text{ atm}\cdot\text{m}^3/\text{mol}$ at 25°C (Mackay and Wolkoff, 1973; Hine and Mookerjee, 1975; Pankow and Rosen, 1988). A compilation of literature values for sorption coefficients suggests that xylenes sorb to soil with approximately the same strength as ethylbenzene (Wiedemeier *et al.*, 1995). Pure xylenes have water solubilities of 152 to 160 mg/L at 20°C (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Isnard and Lambert, 1988). Xylenes can degrade to carbon dioxide via pyruvate carbonyl intermediates (Hopper, 1978; Ribbons and Eaton, 1992).

On the basis of these physiochemical characteristics, RNA, bioventing, SVE, and biosparging could all be effective options for collecting, destroying, and/or treating BTEX at Building 1212. Some of these options are considered less desirable after considering site-specific conditions (Section 6.2.3).

6.2.3 Site-Specific Conditions

Three general categories of site-specific characteristics were considered when identifying remedial approaches for comparative evaluation as part of this demonstration. The first category was physical characteristics such as groundwater depth, hydraulic conductivity, gradient, flow direction, and soil type. The second category was the site geochemistry, or how the site contaminants are interacting with electron acceptors, microorganisms, and other site contaminants. Both of these categories influence the types of remedial technologies most appropriate for the site. The third category involved assumptions about future land use and potential receptor exposure pathways. Each of these site-specific characteristics has influenced the development of remedial alternatives included in the comparative evaluation.

6.2.3.1 Physical Characteristics

Site geology and hydrogeology have a profound effect on the transport of contaminants and the effectiveness and scope of required remedial technologies at a given site. Hydraulic conductivity is perhaps the most important aquifer parameter governing groundwater flow and contaminant transport in the subsurface. The velocity of the groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. The estimated average hydraulic conductivity at Building 1212 is 0.0007 ft/min (1.0 ft/day) (Section 3.3.2.2), which is characteristic of clayey silt (Freeze and Cherry, 1979). This contributes to a slow advective groundwater velocity, estimated at 40 ft/yr.

Although the relatively low hydraulic conductivities in the source area can limit plume expansion and migration, this same characteristic also can reduce the effectiveness of other remedial technologies, such as groundwater extraction and biosparging. For example, it would be more expensive and time-consuming to capture and treat a contaminant plume using a network of extraction wells in an area of low hydraulic conductivity because more wells would be required to envelope the necessary area of influence and sustain a sufficient flow rate. The effectiveness of biosparging also is reduced in low-conductivity aquifers because the increased entry pressures required to introduce oxygen into the groundwater may cause short-circuiting within the well borehole. In addition, the lower hydraulic conductivity would restrict the area of pumping influence of each well, resulting in an increase in the required number of well points to reduce the dissolved contaminant mass throughout the plume.

Given a low groundwater velocity, the effectiveness of natural attenuation can increase as a result of increased contact time with electron acceptors and microorganisms. The slow movement of contaminant mass within the subsurface beneath the source area also limits plume expansion and migration. The plume emanating from Building 1212 is not expected to approach downgradient environmental receptors because of the slow groundwater velocity and the considerable distance to the nearest potential receptor exposure point (3000 feet).

Like hydraulic conductivity, the organic carbon content of native phreatic zone soils can affect the effectiveness of remedial alternatives. The TOC of soils across the phreatic surface in the study area have a low organic carbon content (averaging approximately 0.05 percent), and therefore, the soils have a correspondingly low sorptive potential. However, sorptive capacity is sufficient to cause a difference in the groundwater and contaminant velocities. The difference between contaminant and groundwater velocity increases the effectiveness of biodegradation in the source area because there are fresh electron acceptors flowing past the slower moving dissolved contaminant mass.

6.2.3.2 Geochemical Characteristics

To satisfy the requirements of indigenous microbial activity and RNA, the aquifer also must provide an adequate and available carbon or energy source (e.g., fuel hydrocarbon contamination), electron acceptors, essential nutrients, and proper ranges of pH, temperature, and redox potential. Data collected as part of the field work phase of this demonstration project and described in Sections 3 and 4 of this TS indicate that this site is characterized by adequate and available carbon/energy sources and electron acceptors to support measurable biodegradation of fuel hydrocarbon contamination by indigenous microorganisms. DO, nitrate, sulfate, and methane represent sources of significant electron acceptor capacity for the biodegradation of BTEX compounds at Building 1212 (Table 4.6). The average pH in shallow site groundwater ranged between 6.4 to 7.6 standards units, with the exception of a 9.1 measurement, in May 1996, which is within the optimal range for biodegradation of 6 to 8 standard pH units (Wiedemeier *et al.*, 1995). As pH values drop below 6 standard units, bacteria populations can be expected to decrease, which in turn would reduce the rate of BTEX biodegradation. Redox potentials ranged from 149 to -121 mV in May 1996 (Figure 4.8), and suggest a groundwater environment that is both oxidizing and reducing. The redox potentials at the site suggest that aerobic biodegradation, nitrate reduction, sulfate reduction, and

methanogenesis (consistent with observed geochemical indicator trends discussed in Section 4), would reduce fuel contamination in groundwater. Groundwater data presented in Section 4 strongly support the conclusion that aerobic, nitrate-reducing, sulfate-reducing, and methanogenic processes are reducing BTEX contamination given the current geochemical conditions.

Microbe addition was not considered a viable remedial approach for this site on the basis of observed geochemical trends that suggest that significant microbial activity is likely occurring. *Fuel-hydrocarbon-degrading microorganisms* are ubiquitous in the subsurface, and as many as 28 hydrocarbon-degrading isolates (bacteria and fungi) have been discovered in different soil environments (Davies and Westlake, 1979; Jones and Eddington, 1968). Indigenous microorganisms have a distinct advantage over microorganisms injected into the subsurface to enhance biodegradation because indigenous microorganisms are well adapted to the physical and chemical conditions of the subsurface in which they reside (Goldstein *et al.*, 1985).

6.2.3.3 Potential Receptor Exposure Pathways

A pathways analysis identifies the potential human and ecological receptors that could come into contact with site-related contamination and the pathways through which these receptors might be exposed. To have a completed exposure pathway, there must be a source of contamination, a potential mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements do not exist, the exposure pathway is considered incomplete, and receptors will not come into contact with site-related contamination. Evaluation of the potential long-term effectiveness of any remedial technology or remedial alternative as part of this demonstration project includes determining the potential for pathway completion. If a completed exposure pathway exists (e.g., surface water contact), potential long-term remedial options may still be sufficient to maintain exposure concentrations below regulatory action levels. Establishing site-specific, risk-based cleanup levels is beyond the scope of this TS.

Assumptions about current and future land uses at a site form the basis for identifying potential receptors, potential exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1991) advises that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be

expected to occur should be used to guide the identification of potential exposure pathways and to determine the level to which a site must be remediated.

Building 1212 is surrounded by Base operations buildings, storage yards, and intervening relatively undeveloped areas for at least 5,000 feet east of the site. Fairchild AFB guest accommodations are located approximately 1,000 feet west of the site. In the hydraulically connected downgradient directions (east and southeast), these features extend for at least 3,000 feet before the nearest possible groundwater receptor exposure point is reached. Three shallow ponds are located off Base and east of the site, approximately 1,500 feet from the southeastern corner of the Base boundary. Leaching from soil to shallow groundwater is expected to serve as the predominant BTEX release and transport mechanism. Observed BTEX concentrations (Figures 4.2 and 4.3) and modeling results (Section 5) suggest that contaminant concentrations emanating from Building 1212 are attenuated long before reaching these ponds.

Under reasonable current land use assumptions, potential receptors include only Base intrusive worker populations, because the Bioplume II model results suggest that the dissolved BTEX plume will not migrate far enough to pose a threat to potential receptors exposed at the nearest downgradient pond off Base. Workers could be exposed to site-related contamination in phreatic soils or shallow groundwater if these materials are removed or exposed during future construction excavations or remedial activities. Groundwater from the shallow aquifer is not currently used to meet any demands at Fairchild AFB. All Base potable water is supplied by a Base-owned well field 10 miles northwest of the Base. In addition, there is a water supply well located in the southern area of the Base.

Building 1212 and the surrounding area are proposed to be abandoned in the future because of the inclusion into a Base Explosive Safety Clear Zone. The building, USTs, and fuel distribution systems will be abandoned, and personnel activities will be restricted. The proposed date for these actions is not currently known, but they are expected to occur within the next 5 years. Therefore, potential future receptors are the same as those listed in the preceding paragraph. The potential future exposure pathways involving Base workers are identical to those under current conditions provided shallow groundwater is not used to meet industrial water demands. In summary, the use of RNA at this site will require that the source area be maintained as industrial property, and that restrictions on shallow groundwater use be enforced in areas downgradient from the site until RNA and/or engineered source removal can reduce contaminants to regulatory

action levels. If source reduction technologies such as soil vapor extraction, bioventing, or excavation are implemented, they will have some impact on the short- and long-term land use options, and some level of institutional control and worker protection during remediation may be required.

6.2.3.4 Remediation Goals for Shallow Groundwater

The federal MCLs as listed in 40 CFR 141-61(a) for BTEX and other VOCs (BNA, 1996) are adopted as the state water quality MCLs by the Washington State Department of Health (Title 246-290-310 of the Washington Administrative Code). MCLs for the BTEX compounds are presented in Table 6.1. Model results suggest that without engineered source removal, benzene will remain within the source area in excess of its MCL of 5 µg/L for an estimated 34 years. The toluene concentrations in all Building 1212 groundwater samples are currently below the MCL of 1,000 µg/L. Ethylbenzene and total xylenes exceed their MCLs of 700 µg/L and 10,000 µg/L, respectively, in a groundwater sample from well MW-1(S). Ethylbenzene and xylene are below the MCLs in all remaining groundwater samples. Viable remedial alternatives must be able to achieve MCLs or other risk-based standards that are protective of human health and the environment. Use of risk-based cleanup goals developed specifically for Building 1212 groundwater may permit less stringent groundwater quality standards and further reduce the time required for groundwater remediation and LTM.

Although it is unlikely that groundwater from Building 1212 would be ingested by humans because of Base security and current land use restrictions, the state MCL of 5 µg/L for benzene will be used to evaluate the effectiveness, implementability, and cost of remedial alternatives in this TS; however, site data for benzene suggest that use of the benzene MCL may be overly conservative with respect to the risk to human health based on reasonably conservative groundwater model predictions. If groundwater concentrations protective of human health and the environment can be negotiated with the state on the basis of site-specific exposure scenarios, the time and cost of the proposed remedial alternative (Section 6.5) could potentially be decreased.

TABLE 6.1
GROUNDWATER QUALITY STANDARDS
BUILDING 1212
REMEDATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, MASSACHUSETTS

Compound	State Maximum Contaminant Level ($\mu\text{g/L}$) ^{a/}
Benzene	5
Toluene	1,000
Ethylbenzene	700
Xylenes	10,000

^{a/} Source: WAC 246-290-310

For this TS, the primary remedial objective for shallow groundwater is to reduce contaminant concentrations in groundwater to below federal and state regulatory criteria at a downgradient POC. To accomplish this, remedial alternatives focus on removing or reducing the residual source soil concentrations within the source area at Building 1212 while relying on RNA to limit migration of the dissolved contaminant plume. Active groundwater pumping and/or engineered *in situ* treatment was not considered because of relatively small dissolved plume and the low hydraulic conductivity within the shallow aquifer.

In summary, available data suggest that completed exposure pathways involving human and ecological receptors exposed to contaminated groundwater or surface water do not exist under current conditions. The Building 1212 facility is scheduled to be deactivated and will be designated as a secured area as part of the inclusion into the explosive safety zone. Thus, institutional controls associated with the inclusion into an explosive safety zone are likely to limit any future intrusive activity at the site. The required period of any groundwater and soil institutional controls associated with the selected remedial technology is likely to expire before any anticipated future land use changes.

6.2.4 Summary of Remedial Option Screening

Several remedial options have been identified and screened for use in treating the shallow groundwater at the site. Table 6.2 identifies the initial remedial technologies and approaches considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the program objectives of the AFCEE RNA demonstration, physiochemical properties of BTEX, and other site-specific characteristics such as hydrogeology, geochemistry, land use assumptions, potential receptor exposure pathways, and appropriate remediation goals. All of these factors will influence the technical effectiveness, implementation, and relative cost of technologies for remediating shallow groundwater underlying and migrating from the site. The remedial options retained for development of remedial alternatives and comparative analysis include institutional controls, natural attenuation, LTM, bioventing, and excavation with off-Basesite treatment.

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into three remedial alternatives for the study area. Sufficient information on each remedial alternative is provided to facilitate a comparative analysis of effectiveness, implementability, and cost in Section 6.4.

6.3.1 Alternative 1 - RNA and Institutional Controls with Long-Term Groundwater Monitoring

RNA is achieved when natural attenuation mechanisms bring about a reduction in the total mass of a contaminant in the soil or dissolved in groundwater. RNA results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution (caused by dispersion and infiltration), and volatilization. In some cases, RNA will reduce dissolved contaminant concentrations below numerical concentration goals intended to be protective of human health and the environment. As indicated by the evidence of RNA described in Section 4, these processes are occurring in the vicinity of Building 1212 and will continue to reduce contaminant mass in the plume area.

TABLE 6.2
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
 BUILDING 1212
 REMEDIATION BY NATURAL ATTENUATION TS
 FAIRCHILD AFB, WASHINGTON

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Long-Term Monitoring	Periodic Groundwater Monitoring	Confirmation Wells	All of the existing wells are available to confirm the progress of remediation. Sufficient space exists for additional wells to surround the plume.	Necessary for all remediation strategies	Low	Yes
		Sentry Wells	Sufficient distance exists between the plume and any probable points-of-compliance to locate several sentry wells.	Demonstrate remedial compliance	Low	Yes
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	The plume lies within the Base boundary; however, the Base plans to demolish the facility within 5 years due to inclusion into the explosive safe clear zone. Site access will be highly restricted	Necessary due to change in land use	Low	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area.	Not required at this site	Low	No
		Point-of-Use Treatment	No shallow groundwater is extracted from the plume area for any use.	Poor	Moderate	No
		Meetings/Newsletters	Base environmental offices have many information avenues to workers and residents.	Necessary	Low	Yes
Containment of Plume	Hydraulic Controls	Interceptor Trench Collection	Low hydraulic conductivity of site soils would limit the amount of water collected. Plume migration is minimal and remains confined to the immediate site vicinity.	Low	Moderate	No
		Minimum Pumping/Gradient Control	Site hydrogeologic conditions would not allow for extraction of sufficient volumes. Treatment of extracted water would be necessary. The lack of significant plume migration indicate that this more aggressive remedial option is not necessary.	Low	High	No
	Physical Controls	Slurry Walls/Grout Curtains	Requires significant disruption of site. Plume migration is minimal due to low hydraulic conductivity of aquifer.	Low	High	No
		Sheet Piling	Requires significant disruption of site. Plume migration is minimal due to low hydraulic conductivity of aquifer.	Low	High	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION

BUILDING 1212
 REMEDIATION BY NATURAL ATTENUATION TS
 FAIRCHILD AFB, WASHINGTON

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Containment of Plume (cont.)	Reactive/Semi-Permeable Barriers	Biologically Active Zones	Degradation of BTEX can be stimulated by allowing groundwater to flow through a nutrient-rich barrier. Rate of groundwater migration through barrier would be slow. New, unproven technology.	Moderate	High	No
In Situ Groundwater Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen and/or nutrients are injected downgradient of plume to limit plume migration by enhancing biodegradation and reducing BTEX concentrations as the plume moves down gradient from the source area. Limited radius and short circuiting are problems. Not proven to be more effective than intrinsic remediation.	Moderate to Low	Moderate	No
	Chemical/Physical	Natural Attenuation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Groundwater sampling at Building 1212 indicates that this is a successful ongoing remediation process.	Moderate	Low	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of BTEX into air bubbles and into vadose zone. Limited radius of influence was observed in a pilot test at another Fairchild AFB site with similar soils. Short-circuiting also is a common problem.	Low	High	No
Aboveground Groundwater Treatment	Groundwater Extraction	Vertical Pumping Wells	A part of or the entire groundwater plume is pumped by installing numerous wells with submersible pumps. Eventually would produce a large volume of water which would require additional treatment. Site hydraulics would limit collection of groundwater	Moderate	High	No
	Biological	Bioreactors	Low groundwater flow rates would require excessive remediation times. BTEX is often volatilized in these systems. Groundwater extraction not selected as a remedial option.	Moderate	High	No
	Chemical/Physical	Air Stripping	Cost-effective technology for removing varying concentrations of BTEX at higher flow rates. Groundwater extraction not selected as a remedial option.	Moderate to High	Moderate	No
		Activated Carbon	Cost prohibitive for more concentrated BTEX or long system operation times. Creates a carbon disposal problem. Groundwater extraction not selected as a remedial option.	High	High (O&M)	No

TABLE 6.2 (Concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION

BUILDING 1212
 REMEDIATION BY NATURAL ATTENUATION TS
 FAIRCHILD AFB, WASHINGTON

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Aboveground Groundwater Treatment (cont.)	Chemical/Physical (cont.)	UV/Ozone Reactors	High flow rates require excessive retention times and large, expensive reactors. Groundwater extraction not selected as a remedial option.	Moderate	High	No
		Direct Discharge to a Industrial Wastewater Treatment Plant	Viable option when an IWWTP is readily available and capable of handling BTEX and hydraulic loading. IWWTP not readily available for this site. Groundwater Extraction not retained as a remedial option	High	High	No
Treated Groundwater Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when an IWWTP is available and capable of handling BTEX. Groundwater Extraction not retained as a remedial option	High	High	No
		Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. Groundwater Extraction not retained as a remedial option	High	Low	No
	Treated Groundwater Reinjection	Vertical Injection Wells	Not recommended due to clogging and high maintenance. Groundwater Extraction not retained as a remedial option	Moderate	High	No
		Injection Trenches	Require large trenches and can be subject to injection well permitting. Groundwater Extraction not retained as a remedial option	Moderate	High	No
	Discharge to Surface Waters	Storm Drains	Viable option but generally requires NPDES discharge permit. Groundwater Extraction not retained as a remedial option	High	Low	No
Source Removal/Soil Remediation	In Situ	Bioventing	Air injection/extraction to increase soil oxygen levels and stimulate biodegradation of fuel residuals.	Moderate	Low	Yes
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites for BTEX. Typically requires off-gas treatment.	High	Moderate	No
	Excavation/Treatment	Excavation	Viable option when soils can be disposed of and/or landfarmed near site. Source removal could be accomplished using less intrusive methods.	High	Moderate	Yes
		Soil Washing	Additional pore volumes of water and/or surfactant solution are forced through aquifer material to enhance hydrocarbon partitioning into groundwater.	Low	High	No

Model RNA is intended to predict the fate and transport of dissolved BTEX compounds if engineered remedial action is not implemented at Building 1212. To accomplish this, the model assumed continued releases of fuels to soils surrounding the USTs and fuel distribution systems from 1960 to 1995. In 1995, the fuel distribution and storage systems were replaced or removed and unweathered contaminant loading into the site soils stopped. Because the fuel spill history of Building 1212 is not well documented, modeled source loading at the site during the period from 1960 to 1995 was conservatively maintained at a steady-state rate to approximate the plume shape observed in May 1996.

Results of model RNA suggest that the groundwater contaminant plume emanating from the former USTs and dispensers is mostly attenuated within 75 feet of the source area, and the groundwater plume will disappear following simulation year 34 (calendar year 2030). The model suggests that the plume will not migrate further than the observed May 1996 position, as described in Section 5.6.

Implementation of Alternative 1 would require the use of institutional controls such as land use restrictions and LTM. Land use restrictions may include placing long-term restrictions on soil excavation within the source area and long-term restrictions on groundwater well installations within and downgradient from the plume area. The intent of these restrictions would be to reduce potential receptor exposure to contaminants by legally restricting activities within areas affected by site-related contamination.

Long-term monitoring would be conducted biannually as part of this remedial technology to evaluate the progress of natural attenuation processes and to ensure that remedial objectives are being met. Based on the potential plume migration suggested by the modeling, it is unlikely that benzene concentrations exceeding the indicated Washington groundwater MCL would approach a potential receptor exposure point. This would be true even if it were assumed that simulated contaminant concentrations consist entirely of benzene rather than a mixture of the BTEX compounds. Because there are no apparent downgradient receptor, three sentry wells should be designated downgradient of the current plume front and one sentry well should be installed in the shallow basalt bedrock below the site. In addition, 9 LTM wells within, upgradient, and immediately downgradient from the existing contaminant plume would be used to monitor the effectiveness of RNA within the surficial aquifer. Additional details (including monitoring locations) for LTM of groundwater are provided in Section 7.2. Detection of benzene in excess of 5 µg/L at the furthest downgradient LTM well or the sentry wells

may require additional evaluation to assess BTEX migration and to determine the probable extent of migration, or to determine if additional corrective action is necessary. Regulatory standards for other detected fuel compounds are much higher; therefore, it is unlikely that these standards would be exceeded sooner than would the benzene standard. In either case, land use restrictions would require reevaluation.

Public education on the selected alternative would be developed to inform Base personnel and residents of the scientific principles underlying source reduction and RNA. This education could be accomplished through public meetings, presentations, press releases, and posting of signs where appropriate. Periodic site reviews also could be conducted every year using data collected from the long-term groundwater and surface water monitoring program. The purpose of these periodic reviews would be to evaluate the extent of contamination, assess contaminant migration and attenuation through time, document the effectiveness of source removal and/or institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

6.3.2 Alternative 2 - Bioventing in Source Area, RNA, and Institutional Controls with Long-Term Groundwater Monitoring

This alternative is identical to Alternative 1 except that bioventing would be used to enhance the biodegradation of organic contaminants in subsurface soils by supplying oxygen to indigenous microbes using low-flow air injection in the vicinity of Building 1212. Bioventing is preferred over soil vapor extraction because bioventing uses a low rate of air injection that significantly reduces emissions into the atmosphere while maximizing *in situ* biodegradation. However, air monitoring would be necessary during system start because of the possible migration of potentially combustible vapors from the vadose zone into Building 1212. If hazardous soil vapor were to enter Building 1212, the bioventing system could be run in reverse as a soil vapor extraction (SVE) system until VOC concentrations in soil vapor were reduced.

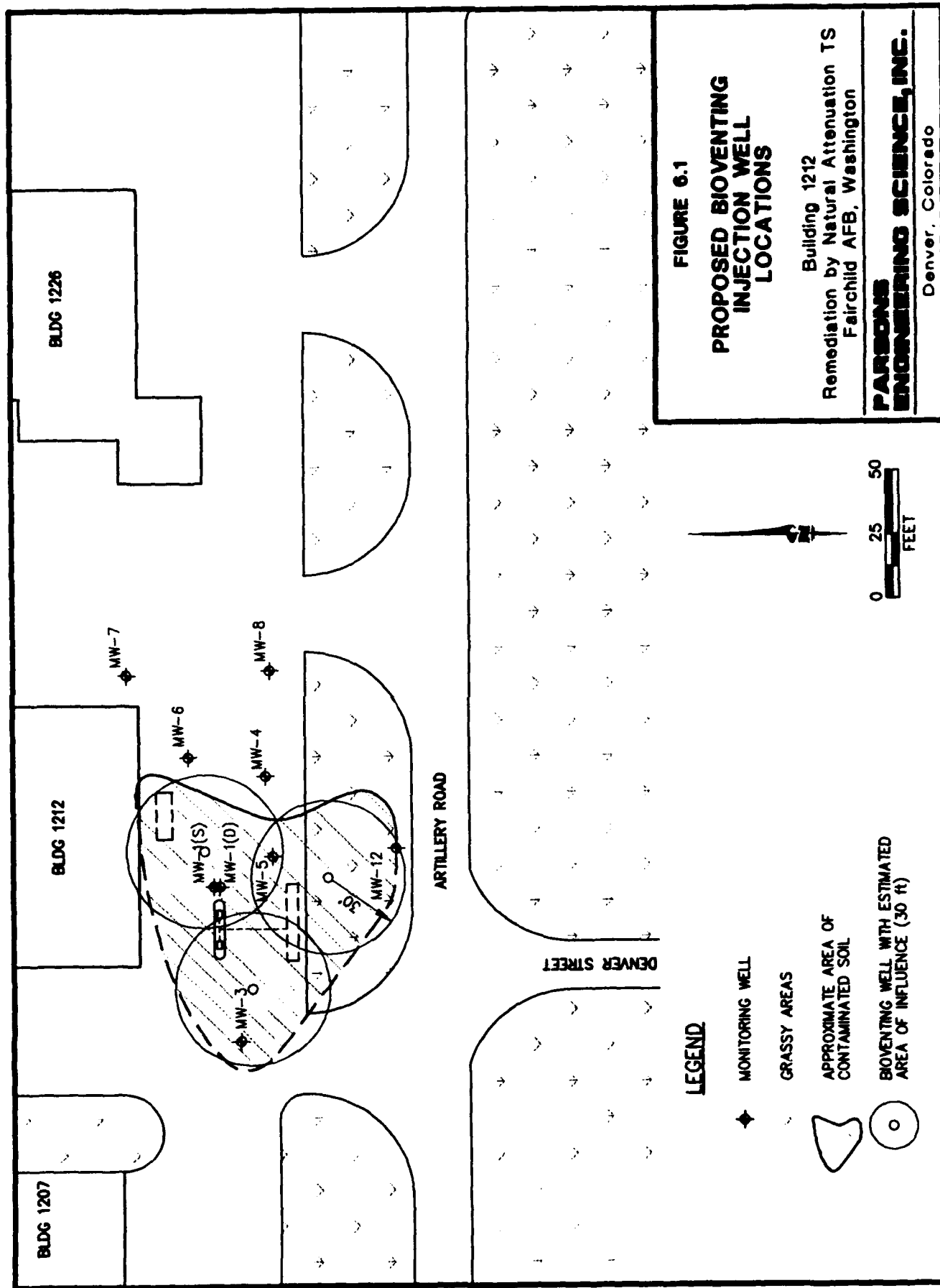
On the basis of Parsons ES experience in the application of soil bioventing technology, three vertical air injection wells installed within the area of contaminated vadose zone soils should be sufficient to remediate the contaminated soil surrounding the former USTs and fuel distribution systems. The depth of each well would be approximately 10 feet bgs. Approximately five shallow vapor monitoring points also would be installed for measurement of the effectiveness of the injection wells. Parsons ES (ES, 1994) has

installed four similar systems at Fairchild AFB fuel spill sites FT-01, Building 2034, Building 2035, and PS-2.

A bioventing system should remove at least 95 percent of residual soil BTEX compounds within 1 to 3 years. Bioventing pilot tests conducted in vadose zone sands at four other Fairchild AFB fuel spill sites had air injection radii of influence ranging from 45 to 60 feet (AFCEE, 1994). The clayey silt underlying the vadose zone sands (Figure 3.3) would likely have a smaller radius of influence when dewatered during low groundwater table conditions. For the purpose of this remedial alternative comparison, air injection wells with a 30-foot radius of influence with an injection rate of approximately 1 pore volume per day [5.2 standard cubic feet per minute (scfm)] have been assumed. Figure 6.1 shows a proposed 3 well bioventing system. Bioventing systems frequently result in BTEX removal efficiencies in vadose zone soils of greater than 90 percent during the first year of operation (AFCEE, 1994). To conservatively estimate remediation costs the system was assumed to operate with a 30-foot radius of influence for 5 years.

To estimate the impact of bioventing on the fate and transport of dissolved BTEX in the shallow groundwater, model Biovent incorporated a decaying BTEX injection rate of 50 percent per year for 5 years. This rate is intended to be a conservative reflection of the 90-percent source reduction in the vadose zone soils in combination with a much lower source reduction in the phreatic soils. Model results suggest that maximum dissolved BTEX concentrations will rapidly decrease in the source area, with downgradient concentrations decreasing at a slightly slower rate. Five years after the implementation of bioventing, the maximum dissolved BTEX concentration is predicted to have fallen to approximately 10 percent of the current maximum concentration. The downgradient extent of the dissolved BTEX plume is predicted to steadily recede for the entire duration of the model. The model predicts the complete degradation of the dissolved BTEX plume in just over 9 years.

As with Alternative 1, institutional controls and LTM would be required. POC and LTM would be the same as described for Alternative 1.



6.3.3 Alternative 3 - Soil Excavation, RNA, and Institutional Controls with Long-Term Groundwater Monitoring

Excavation would involve the removal of contaminated vadose zone soils in the source area down to the groundwater table (approximately 7 to 10 feet bgs). Some residual LNAPL at the periphery of the excavation and in the smear zone below the groundwater table would be expected to remain. Contaminated soils generated during the excavation would be transported and disposed of off-site. By reducing the quantity of residual LNAPL within the source area soils, excavation would reduce the predicted length of time required for RNA to complete groundwater remediation.

Prior to conducting excavation activities, a site characterization study should be performed to further delineate the extent of contamination present at Building 1212. This site characterization should consist of a soil gas survey to quickly delineate the location of contaminated soils. Analytical soil samples should then be collected in the most contaminated areas and sent to a fixed-base laboratory to quantify the magnitude of soil contamination. The potential volume of soils requiring excavation can then be more accurately estimated.

To estimate the impact of excavation on the fate and transport of dissolved BTEX in the shallow groundwater, model Excavate incorporated an instantaneous removal of leachable soil contamination in model year 1. Results suggest that maximum dissolved BTEX concentrations will rapidly decrease at Building 1212, and complete biodegradation of the groundwater plume will occur after model year 6 [3 years earlier than was predicted for bioventing with RNA (Alternative 2)].

As with Alternative 1, institutional controls and LTM would be required. LTM wells would be the same as described for Alternative 1.

6.4 EVALUATION OF ALTERNATIVES

This section provides a comparative analysis of each of the remedial alternatives based on the effectiveness, implementability, and cost criteria. A summary of this evaluation is presented in Section 6.5.

6.4.1 Alternative 1 - RNA and Institutional Controls with Long-Term Groundwater Monitoring

6.4.1.1 Effectiveness

Alternative 1 is based on the effectiveness of natural processes that minimize contaminant migration and reduce contaminant mass over time, and the effectiveness of institutional controls. The effectiveness of RNA was evaluated through Bioplume II modeling presented in Section 5. Model RNA assumes that site remediation relies entirely on natural attenuation mechanisms. Model results predicted that natural attenuation mechanisms will significantly limit BTEX migration and reduce contaminant mass and toxicity. BTEX (and specifically benzene) concentrations should not exceed state MCLs at the sentry wells. Groundwater monitoring at the LTM and POC wells will allow for continued evaluation of BTEX migration and ensure the safety of this alternative. While this alternative would not cease to be protective if the BTEX plume were intercepted by the sentry wells, such an instance would indicate that site conditions should be reevaluated.

The effectiveness of this remedial alternative requires that future intrusive site activities or construction activities within the source area be conducted only by properly protected site workers. Reasonable land use assumptions for the plume area indicate that exposure is unlikely unless excavation or drilling activities bring saturated soil to the surface. Long-term land use restrictions would be required to ensure that shallow groundwater is not pumped or removed for potable use within a radius of approximately 500 feet from the margins of the existing BTEX plume. Existing health and safety plans should be enforced to reduce worker exposures during additional excavation or installing and monitoring additional wells.

Compliance with program goals is one component of the long-term effectiveness evaluation criterion. Alternative 1 would satisfy program objectives designed to promote RNA as a component of site remediation and to scientifically document natural processes; limited drill cutting would be generated during construction of new monitoring wells. This alternative also satisfies program goals for cost effectiveness and waste minimization.

Apart from the administrative concerns associated with the enforcement of long-term land use restrictions and long-term groundwater monitoring programs, this remedial

alternative should provide reliable, continued protection. It is assumed that dissolved benzene concentrations will exceed state and federal criteria throughout the plume for approximately 34 years under alternative 1. Furthermore, it is assumed that sampling will be performed every second year for 34 years to demonstrate that RNA will uniformly reduce all dissolved BTEX compounds to levels below regulatory criteria.

6.4.1.2 Implementability

Alternative 1 is not technically difficult to implement. Installation of any additional LTM wells and monitoring of groundwater and surface water are standard procedures. Long-term management efforts would be required to ensure proper sampling procedures are followed. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and verify the effectiveness of this remediation approach. There also may be administrative concerns associated with long-term enforcement of groundwater use restrictions. Future land use within the source area may be impacted by leaving contaminated soil and groundwater in place. The site is scheduled to be abandoned because of the recent inclusion in the Base explosive safety zone. After abandonment, site access will be restricted for a majority of the Base population. Therefore, with the exception of any subsurface work at the site, the risk of exposure to fuel hydrocarbons for Base personnel will decrease. If required, the public and the regulators would have to be informed of the benefits and limitations of the RNA option. Educational programs are not difficult to implement. Where the effectiveness of this option has been supported, the initial regulatory reaction to this alternative has been positive. Furthermore, because the site will eventually be isolated from the general Base population, the reaction to RNA should be more favorable.

6.4.1.3 Cost

The cost of Alternative 1 is summarized in Table 6.3. Capital costs are limited to the construction of one new bedrock sentry well and three new LTM wells. Included in the \$167,050 total present worth cost estimate for Alternative 1 are the costs of maintaining institutional controls and long-term groundwater monitoring at 13 LTM and sentry wells for a total of 34 years. LTM monitoring at Site Building 1212 is expected to be eliminated after 34 years as a result of complete plume remediation through natural attenuation. It is recommended that conditions at Building 1212 be reevaluated after 20 years of LTM because model predictions of the fate and transport of groundwater

contamination at the study area are conservative, and groundwater remediation may be faster than predicted (Section 5.7). If the groundwater plume at the site recedes faster than predicted or disappears after 20 years of LTM, then monitoring may be eliminated.

TABLE 6.3
ALTERNATIVE 1 - COST ESTIMATE
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

<u>Capital Costs</u>	<u>Cost</u>
Design/Construct 4 LTM/Sentry Wells	\$16,760
<u>Monitoring Costs (per Sampling Event)</u>	<u>Cost per Event</u>
Conduct Groundwater Sampling at 13 wells (every other year for 34 years)	\$7,655
Maintain Institutional Controls/Public Education (34 years)	\$5,000
Project Management and Reporting (34 years)	\$8,400
<u>Present Worth of Alternative 1 ^a</u>	\$167,050

^a Based on an annual adjustment factor of 7 percent (USEPA, 1993).

6.4.2 Alternative 2 - Bioventing, RNA, and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

6.4.2.1 Effectiveness

The effectiveness of RNA and institutional controls with LTM was discussed for Alternative 1 in Section 6.4.1.1. Bioventing is an established technology for reducing source contamination and controlling plume migration. The goal of bioventing would be to effect the removal of BTEX from the source area soils so that RNA of dissolved contaminants in the groundwater could proceed without the continual infusion of additional contaminants. The model suggests that reduction of the source would enhance the effectiveness of RNA and expedite the decrease in the size of the BTEX plume.

Alternative 2 should provide reliable, continuous protection with little risk from temporary system failures. This alternative also complies with AFCEE program goals because RNA remains the predominant remediation method for fuel hydrocarbons

dissolved in groundwater at the site. This remedial alternative, however, will result in the generation of contaminated drill cuttings that may require treatment and/or disposal.

6.4.2.2 Implementability

Installing and operating a bioventing system to reduce residual fuel hydrocarbons in the source areas is more complex than Alternative 1; however, major obstacles are not anticipated. The system would be designed on the basis of results from four bioventing systems that previously have been installed at Fairchild AFB. Installation of the bioventing system involves standard engineering design and construction, including the installation of air injection wells, a regenerative blower system, electrical supply, and system integration.

Installation and operation of a bioventing system would require an increased commitment of labor hours and other resources to maintain and monitor the system. Periodic maintenance would be required for the regenerative blower. Weekly system checks are recommended, and operating data such as injection pressures and flow rates would be manually recorded. It is conservatively estimated that the bioventing system would be operational for 5 years. The technical and administrative implementability concerns associated with the vertical groundwater circulation, natural attenuation, and LTM components of this remedial alternative are similar to those discussed for Alternative 1.

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are shown in Table 6.4. The total present worth cost of Alternative 2 is \$204,220. The cost of Alternative 2 is increased from the costs of Alternative 1 by the addition of the bioventing system, including system design, construction, operation, and maintenance. It is assumed that the bioventing system would operate for 5 years after installation. LTM is assumed to occur every second year for 9 years to ensure that natural attenuation is reducing BTEX concentrations to below regulatory criteria throughout the groundwater plume and to verify that contamination does not reach the sentry wells. The capital expense and annual costs for LTM and institutional controls are assumed to be the same as for Alternative 1; however, the present worth of LTM is lower than for Alternative 1 because of the reduction from 34 years of monitoring to 9 years.

TABLE 6.4
ALTERNATIVE 2 - COST ESTIMATE
BUILDING 1212
REMEDATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

<u>Capital Costs</u>	<u>Cost</u>
Design/Construct 4 LTM/Sentry Wells	\$16,760
Design/Construct 3-Well Bioventing System	\$60,400
<u>Operation, Maintenance, and Monitoring Costs</u>	<u>Cost per annum or event</u>
Operate and Maintain Bioventing System (5 years)	\$9,160
Bioventing Annual Report (5 years)	\$4,350
Conduct Groundwater Sampling at 13 wells at (every second year for 9 years)	\$7,655
Maintain Institutional Controls/Public Education (9 years)	\$2,500
Project Management and Reporting (9 years)	\$5,450
<u>Present Worth of Alternative 2 ^{a/}</u>	<u>\$204,226</u>

^{a/} Based on an annual adjustment factor of 7 percent (USEPA, 1993).

6.4.3 Alternative 3 -Excavation, RNA, and Institutional Controls with Long-Term Groundwater Water Monitoring

6.4.3.1 Effectiveness

Soil excavation is an established technology for reducing source contamination and controlling plume migration. The excavation of contaminated soils from the Building 1212 will substantially reduce the mass of soil contamination leaching into the groundwater. This would instantaneously eliminate much of the source of continuing groundwater contamination. Simulating the excavation of contaminated soils, the modeled dissolved BTEX concentrations at Building 1212 are predicted to decline below 5 µg/L after 6 years (Model Excavate, Section 5).

Alternative 3 should provide reliable, continuous protection with little risk from temporary system failures. This alternative, however, does not comply well with all of

the AFCEE program goals because of the generation of soil waste requiring treatment and disposal. As with Alternatives 1 and 2, this alternative would require RNA with LTM and institutional controls to remediate the contaminated groundwater.

6.4.3.2 Implementability

Limited soil excavation would be simple to implement. The option would require onetime excavation and disposal with no future operation and maintenance commitments. The technical and administrative implementability concerns associated with the RNA, LTM, and institutional controls of this remedial alternative are similar to those discussed in Alternatives 1 and 2.

6.4.3.3 Cost

The estimated capital and operating costs of Alternative 3 are shown in Table 6.5. The total present worth cost of Alternative 3 is \$249,000. The cost of Alternative 3 is increased from the costs of Alternative 1 by the addition of the soil excavation and disposal costs. The present worth cost of LTM and institutional controls is lower than Alternatives 1 and 2 because of the reduced groundwater monitoring time. The annual costs for LTM and institutional controls are assumed to be the same as for Alternatives 1 and/or 2.

6.5 RECOMMENDED REMEDIAL APPROACH

Three remedial alternatives have been evaluated for remediation of the shallow groundwater at the study area. Components of the alternatives evaluated include bioventing, excavation, RNA with LTM of groundwater, and institutional controls. Table 6.6 summarizes the results of the evaluation based upon effectiveness, implementability, and cost criteria. Despite the increase in estimated remediation time from Alternatives 2 and 3, the Air Force recommends Alternative 1 as the most cost effective option for risk reduction at the study area.

TABLE 6.5
ALTERNATIVE 3 - COST ESTIMATE
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

<u>Capital Costs</u>	<u>Cost</u>
Design/Construct 4 LTM/Sentry Wells	\$16,760
Excavate Source Area at Building 1212	\$189,606
 <u>Operation, Maintenance, and Monitoring Costs</u>	 <u>Cost per annum or event</u>
Conduct Groundwater Sampling at 13 wells (every second year for 6 years)	\$7,655
Maintain Institutional Controls/Public Education (6 years)	\$5,000
Project Management and Reporting (6 years)	\$5,450
<u>Present Worth of Alternative 3 ^{a/}</u>	\$249,000

^{a/} Based on an annual adjustment factor of 7 percent (USEPA, 1993).

TABLE 6.6
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
GROUNDWATER REMEDIATION
BUILDING 1212
REMEDICATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1 - RNA - Long-Term Monitoring - Institutional Controls	Contaminant mass, volume, and toxicity will be significantly reduced and plume will recede. MCLs for BTEX are not likely to be exceeded at POC wells.	Readily implementable. Long-term management, groundwater use controls and monitoring required for an estimated 34 years. Minimal exposure of site workers if any future excavation is carefully controlled in source area. If MCLs are exceeded at sentry wells, additional remedial work may be required.	\$160,700
Alternative 2 - Bioventing - RNA - Long-Term Monitoring - Institutional Controls	Similar to Alternative 1, with the addition of a soil bioventing system. BTEX mass, volume, and toxicity will be reduced more rapidly than in Alternative 1.	Readily implementable. Installation of bioventing system should present no problems. Bioventing estimated to continue for 5 years. Long-term management, groundwater controls, and monitoring required for an estimated 9 years. If MCLs are exceeded at sentry wells, additional remedial work may be required.	\$197,775
Alternative 3 - Source Soil Excavation - RNA - Long-Term Monitoring - Institutional Controls	Similar to Alternative 2, with excavation of BTEX contaminated soil in the source area instead of bioventing. Contaminant mass, volume, and toxicity will be reduced at a comparable rate to Alternative 2. Creates soil waste requiring additional treatment or disposal.	Readily implementable. Soil excavation should present no technical problems and the other components are the same as above. Long-term management, groundwater controls, and monitoring required for an estimated 6 years. If MCLs are exceeded at sentry wells, additional remedial work may be required.	\$237,800

All three alternatives make maximum use of natural attenuation mechanisms to reduce plume migration and toxicity. In addition, Alternatives 2 and 3 would use active *in situ* and *ex situ* techniques to reduce the magnitude of continuing sources. Implementation of Alternatives 2 and 3 would substantially decrease the time frame for BTEX remediation, but both alternatives would require greater capital expenditures. The recent inclusion and long term future use of the site in an explosive safety buffer zone will further minimize the risks to Base personnel. Alternative 3 is considered the least favorable of the three evaluated alternatives because soil excavation simply transfers contamination to a different location rather than reducing contaminants to innocuous byproducts.

All three remedial alternatives are implementable and effectively reduce potential hydrocarbon migration and toxicity in the groundwater. All three alternatives should be acceptable to the public and regulatory agencies because they are protective of human health and the environment and reduce soil and groundwater contamination. Implementation of Alternative 1, or any of the three alternatives, will require land use and groundwater use controls to be enforced. Groundwater monitoring would be required for the respective projected cleanup periods. The maximum estimated 34-year remediation time for Alternative 1 is considered to be conservative because the model assumes the plume is entirely benzene. Because the current benzene concentrations are less than 17 percent of the total dissolved BTEX at the site, the groundwater model may overestimate the time required to reduce benzene concentrations. Because the 34-year estimate is believed to be conservative, the proposed LTM period is consistent with federal recommendations that proposed or implemented remedial activities at a site should not exceed 30 years in duration (USEPA, 1988). Furthermore, the future land use restrictions imposed by the explosive safety zone inclusion, will likely be more stringent than a groundwater use control.

The final evaluation criterion used to compare each of the remedial alternatives was cost. It is the opinion of the Air Force that the additional costs of Alternatives 2 and 3 do not justify the reduced risk resulting from the decrease in the time required to remediate the dissolved BTEX plume and the residual soil contamination. Future exposure to potential receptors at the site will be minimal because of the recent inclusion in the explosive safety zone. The indefinite future use of the site will be in a secured, low-use area. Access to the site and the surrounding area will be controlled by Base security. Alternative 1 will cost effectively reduce the level of contamination and maintain the necessary degree of protection to potential receptors at the site, and is the recommended

remedial alternative for Building 1212. A LTM plan for groundwater, including a generic SAP, is provided in Section 7.

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the preferred remedial alternative for Building 1212 (RNA and institutional controls with LTM), a long-term groundwater monitoring plan was developed. The purpose of this component of the preferred remedial alternative for the site is to assess conditions over time, confirm the effectiveness of natural processes at reducing dissolved contaminant mass and minimizing contaminant migration, assess compliance with regulatory standards, and evaluate the need for additional remediation.

To demonstrate attainment of site-specific remediation goals and to verify the predictions of the Bioplume II models developed for Building 1212, the LTM plan consists of identifying the location of two separate groundwater monitoring networks and developing a groundwater sampling and analysis strategy. The strategy described in this section is designed to monitor plume migration in the shallow aquifer over time, to verify that RNA is occurring at rates sufficient to protect potential receptors, and to meet regulatory goals. In the event that data collected under this LTM program indicate that the selected remedial alternative is insufficient to protect human health and the environment, contingency controls to augment the beneficial effects of RNA may be necessary.

7.2 MONITORING NETWORKS

Two separate sets of wells will be used at the site as part of remedial alternative 1. The first set will consist of LTM wells located within and peripheral to the observed BTEX plume to verify the results of the Bioplume modeling effort and to ensure that natural attenuation is occurring at rates sufficient to reduce dissolved BTEX concentrations in the source area (i.e., meet the first level of RAOs for the site). This network of wells will consist of eight monitoring wells screened within the shallow aquifer and one well screened at the base of the shallow aquifer to provide confirmation and verification of the quantitative groundwater modeling predictions.

The second set of groundwater monitoring wells are sentry wells that will be located downgradient from the source area in the shallow and deep aquifers. The purpose of the

sentry wells is to verify that no BTEX compounds at concentrations exceeding state and federal MCLs migrate to areas outside of institutional control where groundwater may affect potential receptors (i.e., meet the second level of RAOs for the site). This network will consist of three sentry monitoring wells screened within the shallow aquifer east and southeast of the site and one well screened across the upper basalt bedrock in the source area.

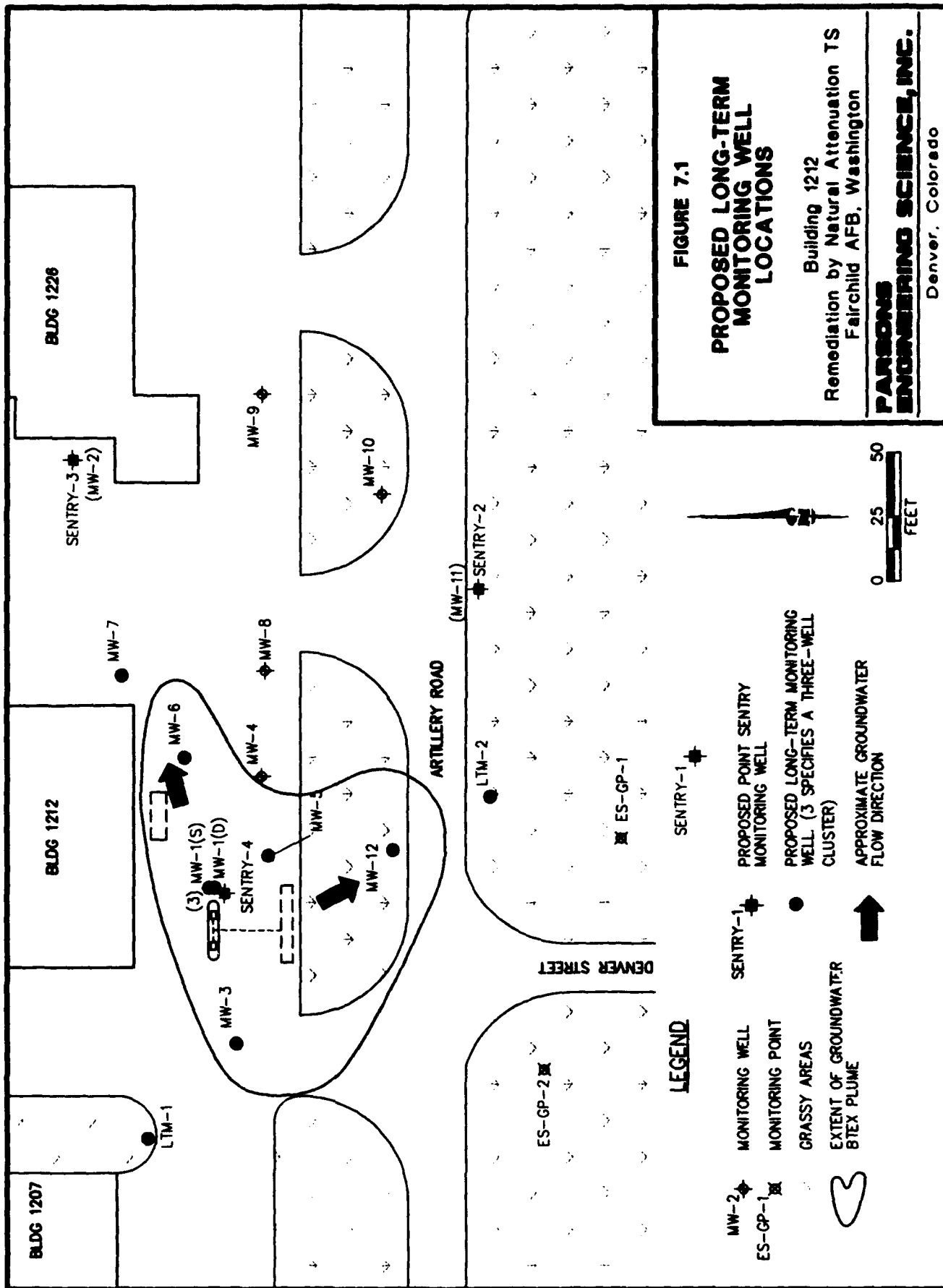
7.2.1 Long-Term Monitoring Wells

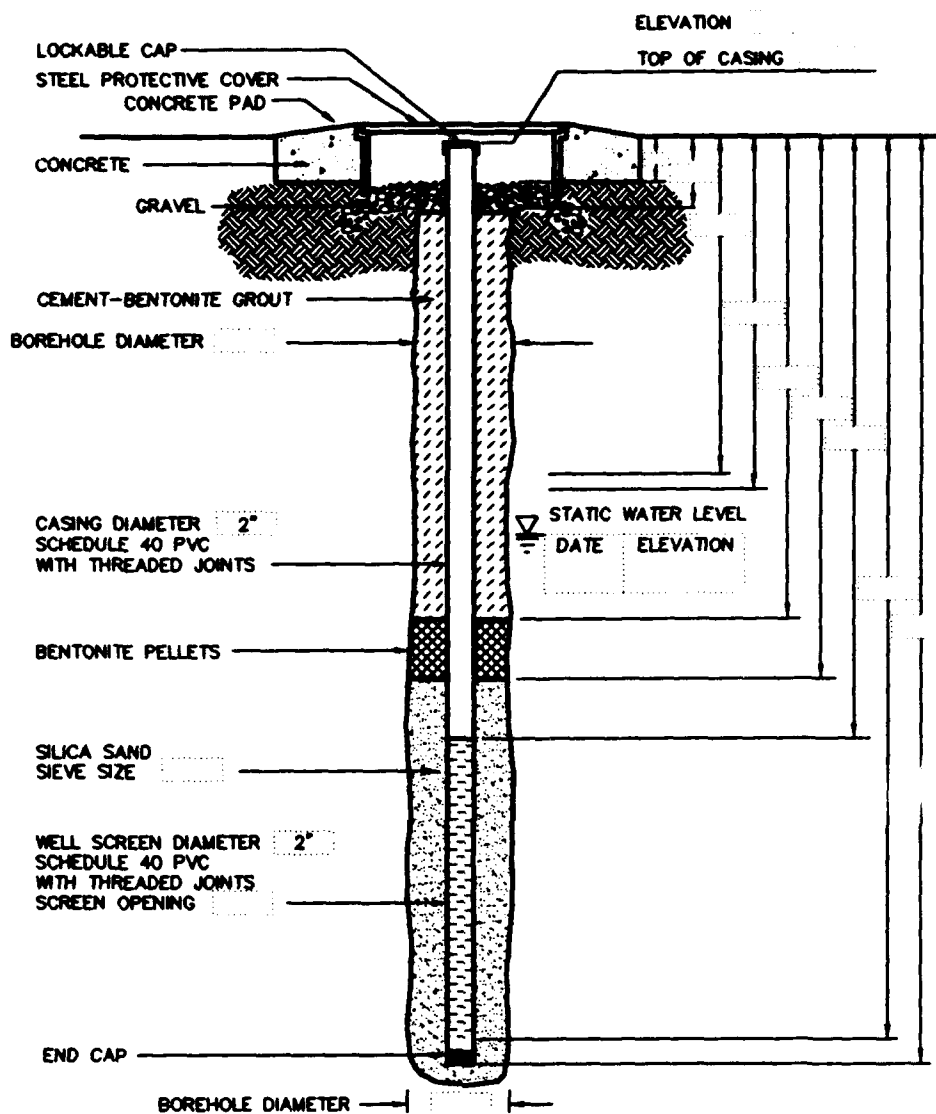
Two proposed and seven existing groundwater wells will be used to monitor the effectiveness of RNA in reducing total contaminant mass and minimizing contaminant migration at Building 1212. One proposed monitoring well will be placed west and northwest of the former gasoline USTs to monitor background groundwater conditions. Monitoring wells MW-1(S) and MW-1(D) will be used to monitor the vertical contaminant extent and the maximum BTEX conditions in the plume source area. Monitoring wells MW-5, MW-6, MW-7, MW-12, and a proposed well will be used to evaluate groundwater conditions along the apparent migration pathways to the east and southeast. Groundwater samples collected from monitoring well MW-3 will determine if any further plume expansion is occurring west of the former gasoline USTs. Figure 7.1 identifies the locations of groundwater monitoring points proposed for LTM. This network will supplement the sentry wells to provide early confirmation of model predictions and to allow additional response time if necessary.

The two new LTM monitoring wells will have 10-foot screened intervals. The wells will be screened across the water table with approximately 8 feet of the 10-foot screen positioned below the water table. A proposed shallow aquifer monitoring well construction diagram is presented on Figure 7.2.

7.2.2 Sentry Wells

Two proposed sentry wells and two existing wells will be used for monitoring groundwater conditions in the shallow aquifer downgradient from the source area at Building 1212 (Figure 7.1). One proposed sentry well will be located approximately 100 feet to the south-southeast of the current BTEX plume extent. Monitoring well MW-11 should be used as a sentry well to ensure that RNA will limit any dissolved plume migration to the southeast. Another proposed sentry well will be designated at monitoring well MW-2 approximately 140 feet to the east-northeast of the former heating oil tank location.





NOT TO SCALE

FIGURE 7.2
SHALLOW AQUIFER
MONITORING WELL
INSTALLATION DIAGRAM

Building 1212
 Remediation by Natural Attenuation TS
 Fairchild AFB, Washington

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

A fourth proposed sentry well is proposed to be installed in the upper basalt bedrock below the source area. Dissolved BTEX is not expected to migrate from the Building 1212 site via the basalt bedrock. However, to ensure that BTEX contamination is not migrating in the upper basalt bedrock, a sentry well should be installed within the upper 20 feet of the basalt bedrock (20 to 40 feet bgs). A diagram of this proposed bedrock well is shown on Figure 7.3.

All four sentry wells are located more than 3,000 feet from any potential groundwater receptor exposure point. If dissolved contaminant concentrations in groundwater samples from the sentry wells should exceed an action level, there would be adequate time to implement corrective action. Figure 7.1 shows the proposed locations of the sentry wells for the shallow aquifer.

The purpose of the sentry wells is to provide information on the direction of plume migration from the source areas and to verify that no contaminated groundwater exceeding state MCLs migrates beyond the area under institutional control. Although model results suggest that the BTEX plume will not migrate beyond its current position in any direction from the source area in the shallow aquifer, these sentry wells are the technical mechanisms used to demonstrate protection of human health and the environment and compliance with site-specific numerical remediation goals.

As with the LTM wells in the shallow aquifer, the two proposed sentry wells in the shallow aquifer will be screened with 10-foot screens intersecting the water table. Data presented in this report concerning the nature and extent of contamination at the site suggest that a 10-foot screen with approximately 8 feet of screen below the groundwater surface of the shallow aquifer will be sufficient to intercept the contaminant plume at this site. MW-11, the third shallow groundwater sentry well, is screened just below the water table.

The proposed upper basalt bedrock sentry well should be installed according to the construction diagram presented on Figure 7.3. The bedrock well should be installed using an outer steel casing extending from the ground surface to a minimum of 2-feet into the basalt bedrock. The steel casing should be backfilled with a cement/bentonite grout that will prevent any shallow aquifer contamination from migrating into the bedrock monitoring well. After the grout has set, a smaller diameter borehole will be advanced through the grout and into the basalt bedrock. Upon inspection of the bedrock hydrogeologic characteristics, a 2-inch Schedule 40 PVC casing with a 10-foot screen interval will be installed.

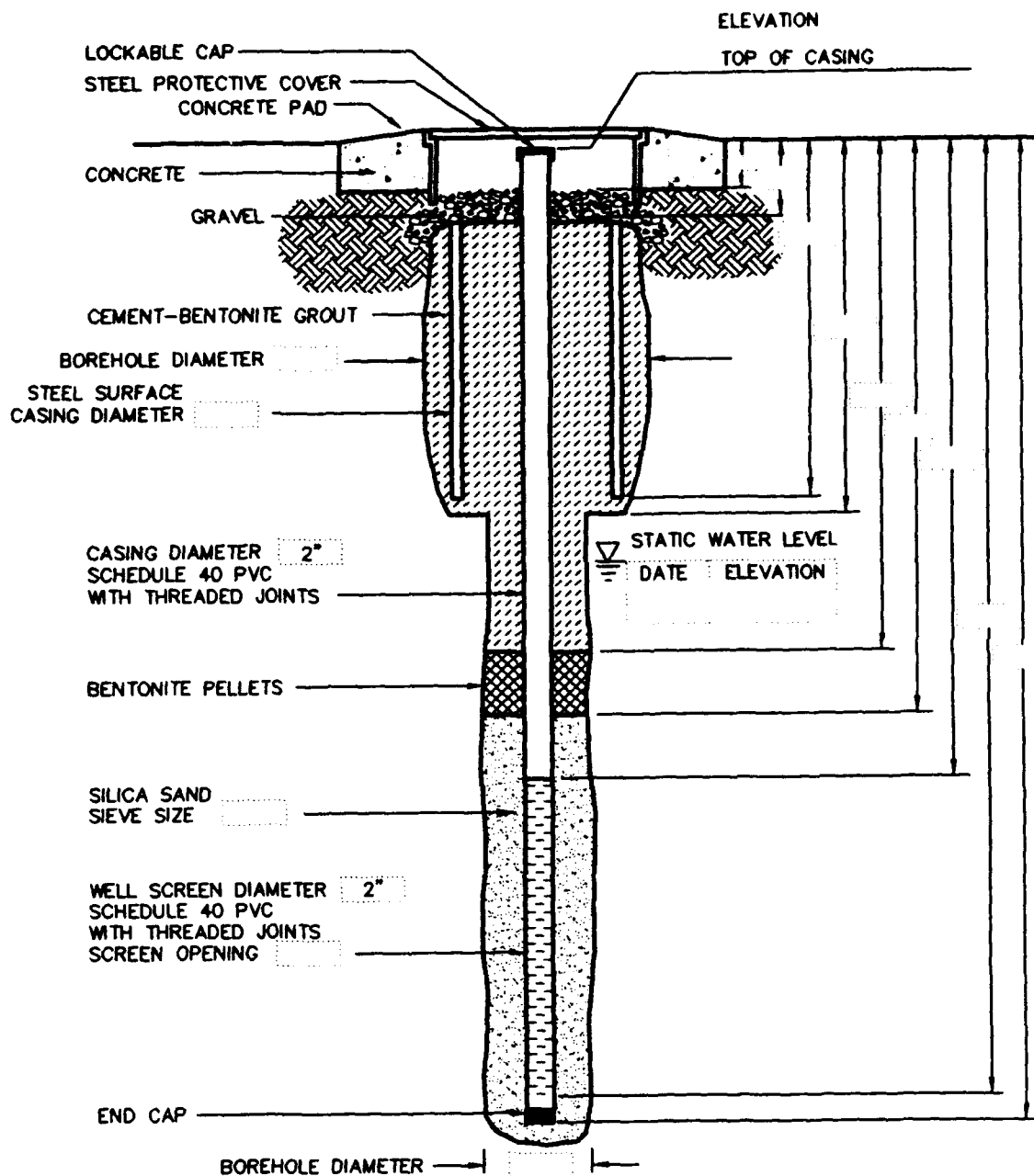


FIGURE 7.3

**PROPOSED BEDROCK
MONITORING WELL
CONSTRUCTION DIAGRAM**

Building 1212
Remediation by Natural Attenuation TS
Fairchild AFB, Washington

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

7.3 GROUNDWATER SAMPLING

To ensure that sufficient contaminant removal is occurring at Building 1212 and to meet site-specific remediation goals, this long-term groundwater monitoring plan includes a general sampling and analysis plan (SAP). LTM and sentry wells be sampled and analyzed every other year to document plume migration and to verify that natural processes are effectively reducing contaminant mass and mobility. Reduction in toxicity will be implied by mass reduction. The SAP also is aimed at assuring that the selected remedial alternative can achieve site-specific remediation concentration goals for BTEX compounds.

7.3.1 Analytical Protocol

All LTM and sentry wells in the LTM program will be sampled and analyzed to determine compliance with chemical-specific state MCLs to verify the effectiveness of RNA at the site. Water level measurements will be made at all site wells during each sampling event. Groundwater samples collected from LTM wells will be analyzed for the parameters listed in Table 7.1. Groundwater samples collected from sentry wells will be analyzed for the parameters listed in Table 7.2. A more detailed site-specific groundwater SAP should be prepared prior to initiating the LTM program.

7.3.2 Sampling Frequency

Each LTM and sentry well location will be sampled once every 2 years for 20 years. If after 20 years, the data collected during this time period support the anticipated effectiveness of RNA at this site, the sampling frequency can be continued at the same frequency, reduced to once every 5 years for all wells in the LTM program, or eliminated. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, sampling frequency should be adjusted accordingly.

TABLE 7.1
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR GROUNDWATER
BUILDING 1212
REMEDIAION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous Iron (Fe ²⁺)	Colorimetric A3500-Fe D	Field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction.	Every second year for 34 years	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field
Ferrous Iron (Fe ²⁺)	Colorimetric Hach® 25140-25	Alternate method; field only	Same as above.	Every second year for 34 years	Collect 100 mL of water in a glass container	Field
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature.	Every second year for 34 years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume II model; concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Every second year for 34 years	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods ^a	Aerobic and anaerobic processes are pH-sensitive.	Every second year for 34 years	Collect 100-250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Every second year for 34 years	Collect 100-250 mL of water in a glass or plastic container	Field
Nitrate	IC method E300 or Hach® Nitrover 5 method	Method E300 is a Handbook method. Hach® method is photometric	Substrate for microbial respiration if oxygen is depleted.	Every second year for 34 years	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for Hach® method)

TABLE 7.1 (Concluded)
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR GROUNDWATER
BUILDING 1212

REMEDATION BY NATURAL ATTENUATION TS
 FAIRCHILD AFB, WASHINGTON

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO_4^{2-})	IC method E300 or method SW9056 or Hach® SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. Hach® method is Photometric	Substrate for anaerobic microbial respiration	Every Second Year for 30 Years	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for Hach® method)
Methane,	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the USEPA Robert S. Kerr Laboratory	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis).	Every Second Year for 30 Years	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV.	Every second year for 34 years	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020 or GC/MS method SW8260.	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX are the primary target analytes for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance.	Every second year for 34 years	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	Fixed-base

a/ Protocol analytical methods are those presented by Wiedemeier *et al.* (1995). Handbook refers to "AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigation/Feasibility Study (RI/FS).

TABLE 7.2
GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR SENTRY WELLS
BUILDING 1212
REMEDIATION BY NATURAL ATTENUATION
FAIRCHILD AFB, WASHINGTON

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature.	Every second year for 34 years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume II model; concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Every second year for 34 years	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods ^{a/}	Aerobic and anaerobic processes are pH-sensitive.	Every second year for 34 years	Collect 100-250 mL of water in a glass or plastic container; analyze immediately	Field
Redox potential	A2580 B	Measurement ^{a/} are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV.	Every second year for 34 years	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020 or GC/MS method SW8260.	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX are the primary target analytes for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance.	Every second year for 34 years	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH \leq 2	Fixed-base
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Every second year for 34 years	Collect 100-250 mL of water in a glass or plastic container	Field

a/ Protocol analytical methods are those presented by Wiedemeier *et al.* (1995). Handbook refers to "AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigation/Feasibility Study (RI/FS).

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate the use of RNA of fuel-hydrocarbon-contaminated groundwater at Building 1212, Fairchild AFB, Washington. Specifically, the finite-difference groundwater model Bioplume II was used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of BTEX compounds dissolved in groundwater.

Geochemical of evidence was used to document RNA at Building 1212. Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps for Building 1212 provides strong geochemical evidence of biodegradation of both BTEX. Geochemical data strongly suggest that biodegradation of fuel hydrocarbons is occurring at the site via aerobic respiration and the anaerobic processes of denitrification, iron reduction, sulfate reduction, and methanogenesis. Rates of biodegradation were estimated from observed contaminant concentrations and the method of Buscheck and Alcantar (1995).

To obtain the data necessary for the RNA demonstration, Parsons ES collected and analyzed soil and groundwater samples from the site. Site-specific geologic, hydrologic, and laboratory analytical data were then used in the Bioplume II numerical groundwater model to simulate the effects of advection, dispersion, sorption, and biodegradation on the fate and transport of the dissolved BTEX plume. Extensive site-specific data were used for model implementation. Model parameters that could not be obtained from existing site data were estimated using widely accepted literature values for aquifer materials similar to those found at the site. Conservative aquifer parameters were used to construct the Bioplume model for this site. Therefore, the model results presented herein represent conservative predictions of groundwater BTEX plume fate and transport.

For one model simulation (model RNA), it was assumed that conditions that produced the calibrated model would persist for the duration of the simulation. This scenario

suggests that the plume is nearly stable and therefore will not migrate much beyond the May 1996 extent. The model predicts complete attenuation of the dissolved BTEX plume in 34 years. Model Biovent assumed a contaminant source reduction through bioventing, using a geometric source decay rate of 50 percent per year for 5 years. Results for this model suggest that the nearly stable plume will rapidly recede after the start of bioventing activities and source area dissolved BTEX concentrations will be below the 5- μ g/L state MCL for benzene 9 years after the implementation of the bioventing/RNA remedial alternative. The third model (Excavate) assumed soil excavation of the source area would completely remove the soil source. Model Excavate predicts that the dissolved BTEX plume will attenuate to below the benzene MCL in just over 6 years.

The results of this study suggest that RNA of dissolved BTEX compounds is occurring at Building 1212. Given that the models predict no impact to known receptors at the modeled rates of BTEX plume migration, the Air Force is recommending RNA, institutional controls, and LTM to remediate site groundwater impacted by BTEX. Because the site was recently included in the Base explosive safety zone, the site will be vacated within the next 5 years, and all future site activities will be supervised by the Base security police. The estimated rates of biodegradation, when coupled with sorption, dispersion, and dilution, should be sufficient to reduce and maintain dissolved BTEX concentrations to levels below current regulatory standards long before potential downgradient receptors could be adversely affected. Construction activities in the plume area and groundwater use in and downgradient from the plume area should be restricted for a period of at least 30 years or until groundwater contaminant concentrations decrease below federal MCLs for BTEX. Currently, the toluene concentrations in all Building 1212 groundwater samples are below the state MCL for toluene. Ethylbenzene and total xylenes exceeded their respective state and federal MCLs in a groundwater sample from one sampling location within the source area. In all remaining groundwater samples, ethylbenzene and xylene were below the MCLs. Benzene was detected above the state MCL in several groundwater samples. Therefore, benzene will likely be the only BTEX compound of concern with respect to any closure activities.

To verify the results of the Bioplume II modeling effort, and to ensure that RNA is occurring at rates sufficient to protect potential downgradient receptors, groundwater from nine LTM wells should be sampled and analyzed for the parameters listed in Table 7.1. In addition, three sentry groundwater monitoring wells should be designated downgradient from the BTEX plume and sampled for the parameters listed in Table 7.2. A fourth sentry well should be installed beneath the source area in the shallow basalt bedrock in the source area to monitor vertical contaminant migration. Prior to the implementation of LTM, the proposed bedrock sentry well could be installed verify that contamination from Building 1212 is not migrating in the basalt bedrock. If contamination is found, the LTM plan for the shallow aquifer would remain valid, and additional bedrock wells would be required. If dissolved contamination is not present, the well should be designated as a sentry well and analyzed for the parameters in Table 7.2. Figure 7.1 shows suggested locations for the sentry and LTM wells. These wells should be sampled every other year for approximately 34 years. After 20 years, the results from LTM should be evaluated to determine whether sampling will cease, will decrease in frequency, or will continue at the rate of every second year. If dissolved BTEX concentrations in groundwater collected from the sentry wells exceed regulatory criteria, additional evaluation or corrective action may be necessary at this site.

SECTION 9

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APPENDIX A
GEOLOGIC LOGS, MONITORING WELL COMPLETION RECORDS
AND SLUG TEST RESULTS

APPENDIX A.1

GEOLOGIC LOGS

GEOLOGIC BORING LOG

BORING NO.: PES-MW-1 CONTRACTOR: Budinger & Assoc DATE SPUD: 5/18/96
 CLIENT: AFCEE RIG TYPE: ? DATE CMPL.: 5/18/96
 JOB NO.: 722450-18 DRLG METHOD: HSA ELEVATION: 55°
 LOCATION: FAIRCHILD AFB BORING DIA.: 6" TEMP: ?
 GEOLOGIST: M. VESSELY DRLG FLUID: none WEATHER: Clear & Breezy
 COMMENTS: Spurred to possibly be saturated w/ fuel @ 2' ? dig to low in clay

Elev (ft)	Depth (ft)	Pro-File	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PH (ppm)	TLV (ppm)	TOTAL BTEX (ppm)	TPH (ppm)
	1			Asphalt - 4"								
			ML	Fil, brown (dark), stiff, moist		2.0'						
				clayey silt, some medium		4.2'						
	5			no odor								
			5'	Clay colored, silty coarse		6.9'			338			
				Sand, moderate odor, slightly					724			
				moist, gravel size stones					467			
	10			Brownish, slightly moist clayey silt,		8.6'			22.5			
				high clay content, (B/S), strong					57.3			
				odor, moist at 11' bgs, med. odor					72.2			
				moderate odor @ 12.5', moist					35.5			
	15			Slight odor @ 15' (B/S) (clay)					2.0			
				Some fine sand 15' (B/S) (clay)								
				Wet								
				Slight odor (7), SAA, wet, some								
				clay pockets								
	20											
				SAA, no odor								
				Black, sandy clay, some highly								
				fragments, moist, brown								
	25			Black, no odor as above								
				fragments @ 24.5' bgs								
				Stronger fragments @ 25.5' SAA,								
				Strong odor, (B/S) fragments								
				22'								
				BOTTOM @ 25.5'								
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.: PES-MW-2 CONTRACTOR: Budinger & Assoc DATE SPUD: 5/18/96
 CLIENT: AFCEE RIG TYPE: Hollow Stem Auger DATE CMPL.: 5/15/96
 JOB NO.: 722450-18 DRLG METHOD: 4SA ELEVATION:
 LOCATION: FAIRCHILD AFB BORING DIA.: 8" TEMP: 65°
 GEOLOGIST: M. VESSELY DRLG FLUID: none WEATHER: Cloudy
 COMMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	POD (ppm)	TLW (ppm)	BTX (ppm)	TOTAL (ppm)	TPH (ppm)
0	1			SPILL									
	5			Brown, granular, Sand, med-coarse fill, gravel > 2" diameter no odor, slightly moist little silt, no clay	5	5.2			0				
~6'				yellow Brown, clayey, fine Sand silt, plastic, moist no odor	7	7.0							
	10			SAA, no odor, moist	9	9.0			0				
				SAA, slightly wet	12	12.0			0				
	15				14	14.0							
					16	16.0			0				
	20			SAA	18	18.0							
					22	22.0			0				
~25.5'	25			fractured, Brown Sand, med-coarse, gravelly (> 2"), BASALT	26	26.5			0				
				BASALT - REFUSAL									
	30												
	35												

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.: PES-MW 3 CONTRACTOR: Industrious & Assoc DATE SPUD: 5/20/96
 CLIENT: AFCEE RIG TYPE: HSA DATE CMPL.: 5/20/96
 JOB NO.: 722450-18 DRLG METHOD: HSA ELEVATION: 2432.26
 LOCATION: FAIRCHILD AFB BORING DIA.: 5" TEMP: 50°
 GEOLOGIST: M. VESSELY DRLG FLUID: None WEATHER: Clear, Breezy
 COMMENTS: Back Ground LOCATION

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PIV(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
6"	1			GRAVELLY, medium to coarse Brown Sand, gravel < 3" diameter, moist, no odor								
	5				X	4	80%					
26.5'						6			6.3			
				CLAY, Brown, clumpy silt, moderate odor, moist to wet, water near 8' has	X	8	92%	6" liner 9"	33.4			
	10					10						
				SAA, slight odor, moist	X	14	100%		11.0			
	15			30" sand, seen @ 15.5'		16						
				SAA		20	100%	6" liner 20.5"	6.6			
21.3'	20			Silty, clay, no odor		21.5						
				BASALT, BLACK, vesicular w/ T, weathered (rust-brown) MATERIAL @ contact								
	25											
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB



Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.: RES-mw-4 CONTRACTOR: Boring of House DATE SPUD: 5/20/76
 CLIENT: AFCEE R/C TYPE: HS-1 DATE CMPL.: 5/20/76
 JOB NO.: 722450-18 DRLG METHOD: HS-1 ELEVATION: 5.1
 LOCATION: FAIRCHILD AFB BORING DIA.: 5" TEMP: 5.1
 GEOLOGIST: M. VESSELY DRLG FLUID: None WEATHER: Clear & Breezy
 COMMENTS:

Elev (ft)	Depth (ft)	Pro file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PH (ppm)	TLV (ppm)	TOTAL BTX (ppm)	IPH (ppm)
6.4	1			5.1" Black, Brown, GRAVELY Sand. No odor, slightly moist								
5.2	5			Tan Brown, Clayey silt, Moist to wet, no odor	41	8.2						
					46							
	10			SAA, Moist, Slight odor	5	10.2						
					7.5							
					10.2							
					11.5							
	15			SAA, no odor	16							
					11.0							
					16							
	20			SAA, no odor	21							
21.5				Weathered Basalt, Rust Brown, CLAY TAPING 2" BASALT FRAGMENTS, no odor, moist	75.5							
					22.5							
	25			Auger Refusal @ 22.5								
				BASALT BED EX. 10								
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB



Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.: PES-MW-5 CONTRACTOR: Boring & Assoc. DATE SPUD: 5/26/76
 CLIENT: AFCEE RIG TYPE: DATE CMPL.: 5/26/76
 JOB NO.: 722450-18 DRLG METHOD: HSA ELEVATION: 2432.33
 LOCATION: FAIRCHILD AFB BORING DIA.: 8 TEMP: 65
 GEOLOGIST: M. VESSELY DRLG FLUID: None WEATHER: Partly Cloudy, Windy
 COMMENTS:

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PIU(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			ASPHALT								
	5			Thin Brown, Gravelly Sand Fill, moist, no odor	4	90%						
27				SAA, slight odor	6				0.3			
	10			GRAY, CLAYEY Silt, moist, Moderate odor	7.5	6"						
	15			SAND, moderate odor, wet	15	100%						
	20			SAA, no odor	17				13.3			
	25			↑ Refusal BASALT Bedrock. weathered Bedrock, no odor	20	100%						
	30				21				12.5			
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.: PES-MW-6 CONTRACTOR: Badinger Bros. DATE SPUD: 5/22/76
 CLIENT: AFCEE RIG TYPE: HSA DATE CMPL.: 5/20/76
 JOB NO.: 722450-18 DRLG METHOD: HSA ELEVATION: 65
 LOCATION: FAIRCHILD AFB BORING DIA.: 8" TEMP: 65
 GEOLOGIST: M. VESSELY DRLG FLUID: None WEATHER: Partly Cloudy Windy
 COMMENTS:

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID (ppm)	TLV (ppm)	TOTL (ppm)	IPH (ppm)
75	1			ASPHALT								
75	5			Fill, brown, gravelly (<2") Sand, slightly moist, no odor	4	100%						
75	6			SAA, no odor	6				0.5			
75	7			Brown, coarse Sand, fill? slight odor	7	100%	6" line		1.5			
75	10			gray, clayey silt, wet Strong odor, some medium Sand	17				1.75			
75	15			SAA, no odor, tan	13	90%			0			
75	20			SAA, Olive, slight odor(?) may not be hydrocarbon	20				0			
75	23.5			SAA, no odor	21							
75	25			Weathered CLAY-BEVEL BASALT	23	100%			1.8			
75	25			Basalt Bedrock	24							
75	30											
75	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.: RES-MW-7 CONTRACTOR: Redinger & Assoc DATE SPUD: 5/21/96
 CLIENT: AFCEE RIG TYPE: DATE CMPL: 5/21/96
 JOB NO.: 722450-18 DRLG METHOD: HSA ELEVATION:
 LOCATION: FAIRCHILD AFB BORING DIA.: 8" TEMP: 45°
 GEOLOGIST: M. VESSELY DRLG FLUID: None WEATHER: Partly Cloudy 4-5
 COMMENTS:

Elev (ft)	Depth (ft)	Pro-File	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	FO (ppm)	TLV (ppm)	TOTAL STD (ppm)	TPH (ppm)
	1											
	5			GRAVELLY SAND, (Fill) must be top of sample, Brown, no odor.	4	4.0	X					
	7.8			S&A	6	6.0			0.3			
	10			Drive, (Gravel, Silt, mud, no odor.	7	7.0	X					
	15			S&A, Brownish	9	9.0			2.8			
	20			↑ Bottom @ 19'	14	14.0	X					
	25				16	16.0			0.0			
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.: FE5 MW-8 CONTRACTOR: Industrious Assoc DATE SPUD: 5/21/96
 CLIENT: AFCEE RIG TYPE: DATE CMPL.: 5/21/96
 JOB NO.: 722450-18 DRLG METHOD: 454 ELEVATION:
 LOCATION: FAIRCHILD AFB BORING DIA.: 5" TEMP: 45"
 GEOLOGIST: M. VESSELY DRLG FLUID: None WEATHER: Partly Cloudy & Windy

COMMENTS:

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID (ppm)	TLV (ppm)	TOTAL BTX (ppm)	TPH (ppm)
6"	1			ASPHALT								
	5			Brown, GRAVELLY (2 1/2"), Sand fill, moist at top of sample. Drier @ bottom. No odor.	4	10"						
7.5				SAA, wet (Drove through water?)	6				0.2			
	10			Gray, Clayey Silt, no odor. Moist	7	10"	6' in 3.5'		2.1			
	15			SAA, moist, no odor.	8	10"			1.6			
	20			SAA No odor	9	10"						
14.5				Weathered, clay-gravel basket	10	10"			2.1			
	25			Basket Rock, Refusal	11	10"						
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.:	PE5 - mu-9	CONTRACTOR:	D. J. Pineda Assoc.	DATE SPUD:	5/21/96
CLIENT:	AFCEE	RIG TYPE:		DATE CML.:	5/21/96
JOB NO.:	722450-18	DRLG METHOD:	145A	ELEVATION:	
LOCATION:	FAIRCHILD AFB	BORING DIA.:	6"	TEMP:	45° - 50°
GEOLOGIST:	M. VESSELY	DRLG FLUID:	none	WEATHER:	Cloudy - windy
COMMENTS:					

[illegible]

bgs - Below Ground Surface
GS - Ground Surface
TOC - Top of Casing
NS - Not Sampled
SAA - Same As Above

D - DRIVE
C - CORE
G - GRAB

 Water level drilled

**Intrinsic Remediation TS
Fairchild AFB, Washington**



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GEOLOGIC BORING LOG

BORING NO.: ES-MW-10 CONTRACTOR: Bridging & Assoc. DATE SPUD: 5/21/77
 CLIENT: AFCEE RIG TYPE: DATE CMPL.: 5/21/77
 JOB NO.: 722450-18 DRLG METHOD: HSA ELEVATION:
 LOCATION: FAIRCHILD AFB BORING DIA.: 8" TEMP: 53
 GEOLOGIST: M. VESSELY DRLG FLUID: None WEATHER: Cloudy, rainy
 COMMENTS:

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PH	TD(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	IPH (ppm)
	1			Top 2' of black, wet fine-grained sand with silt									
	5			Brown, gravelly, coarse sand (< 4" dia.) slightly moist no color	X	6.0				0.3			
				SAA, wet, no color, subbed	X	7.0				0.2			
	10												
				tan brown, clayey silt moist, no color		13.0				0.5			
	15												
				Bottom of Hole									
	20												
	25												
	30												
	35												

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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GEOLOGIC BORING LOG

BORING NO.: P.S. MW 11 CONTRACTOR: Rudolph & Assoc DATE SPUD: 5/21/96
 CLIENT: AFCEE RIG TYPE: _____ DATE CMPL.: 5/21/96
 JOB NO.: 722450-18 DRLG METHOD: ASA ELEVATION: _____
 LOCATION: FAIRCHILD AFB BORING DIA.: 5" TEMP: _____
 GEOLOGIST: M. VESSELY DRLG FLUID: NONE WEATHER: RAIN
 COMMENTS: _____

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TREX(ppm)	TOTAL TPH (ppm)
	1			Top Soil, Brown, Fine-med Silt, wet								
	5			Brown, wet, Gravelly, coarse Sand, no odor.	X	4	60%		0.0			
	7.5			SAA, unsaturated , No odor	X	6						
	10			Brown, moist, Clayey Silt No odor	X	7			0.0			
	15			SAA	X	13			0.0			
	20			Bottom of Hole		75%						
	25					15						
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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 Denver, Colorado

GEOLOGIC BORING LOG

BORING NO.: DES-MW-12 CONTRACTOR: Budington & Associates DATE SPUD: 5/22/76
 CLIENT: AFCEE RIG TYPE: DATE CMPL.: 5/22/76
 JOB NO.: 722450-18 DRLG METHOD: HSA ELEVATION:
 LOCATION: FAIRCHILD AFB BORING DIA.: 8" TEMP: 45°
 GEOLOGIST: M. VESSELY DRLG FLUID: None WEATHER: RAIN, wind
 COMMENTS:

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PIV(ppm)	TLV(ppm)	TOTAL STRENGTH(ppm)	IPH (ppm)
	1											
	5			Black, micaceous, granular Silt, no odor	4	3 1/2						
					6							
					7	9 1/2	GRAB					
	10			Tan, clayey silt, moist, slight odor	9							
	15			SAA slight to no-odor	13							
					15							
	20			SAA, no odor								
				Brown weathered, clay - concrete Basalt	20	20 1/2						
				Basalt Bedrock - Refused C 21'	21							
	25											
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Intrinsic Remediation TS
 Fairchild AFB, Washington



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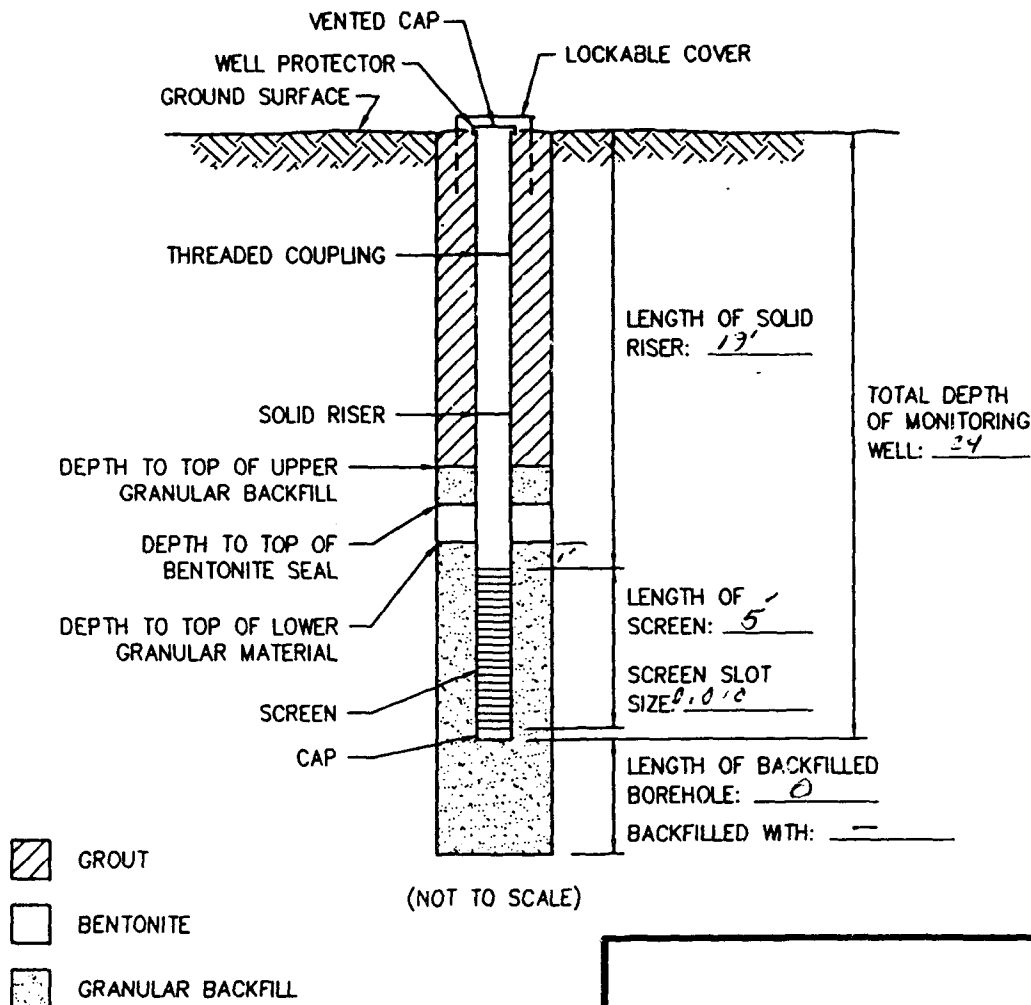
Denver, Colorado

APPENDIX A.2

MONITORING WELL COMPLETION RECORDS

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER PES-MW-1D
 JOB NUMBER 722450.18 INSTALLATION DATE 5/18/96 LOCATION Building 1212
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL 20-40 Sand ES REPRESENTATIVE Wissler/Mickler
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Burlinger/Assec



STABILIZED WATER LEVEL 10.15 FEET 7.45
 BELOW DATUM: bg 3/18/96 17.30
 MEASURED ON _____

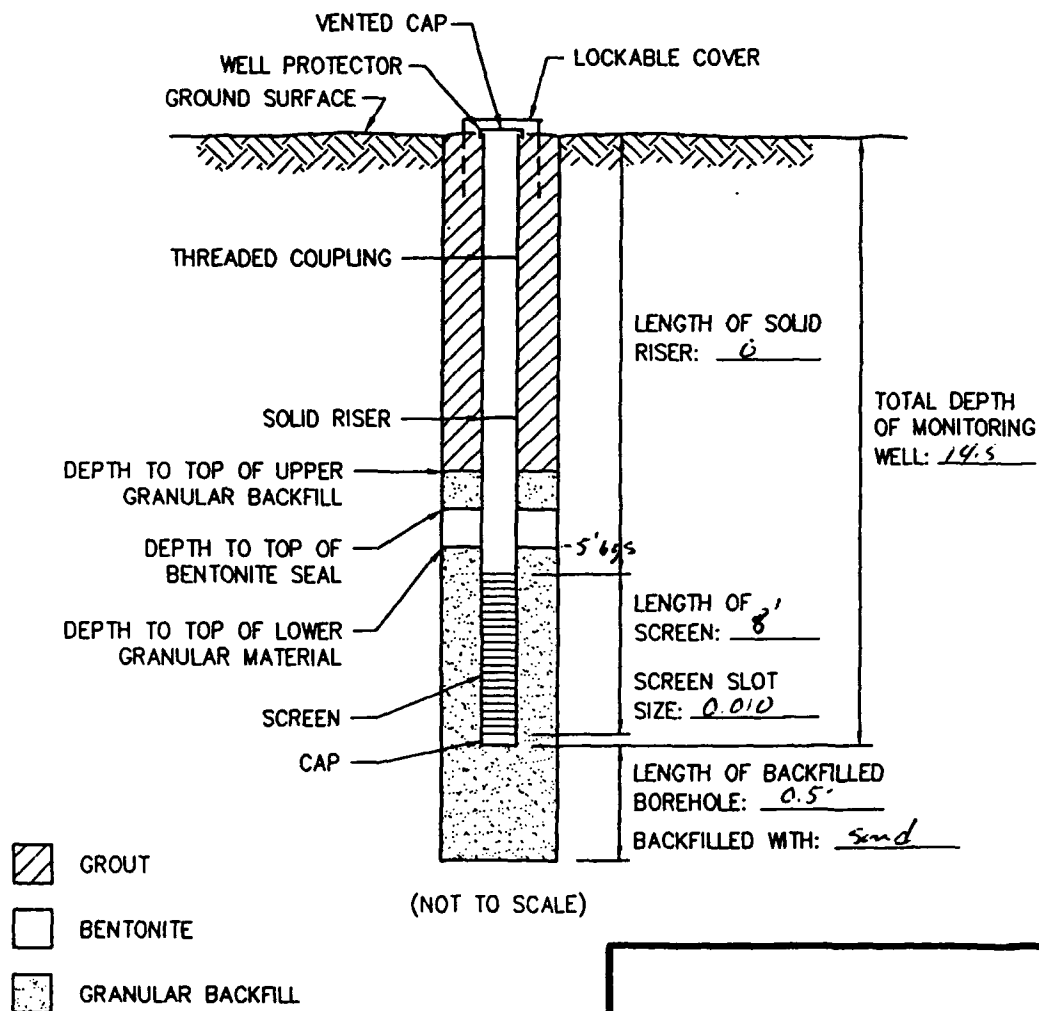
MONITORING WELL INSTALLATION RECORD

Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

PARSONS
ENGINEERING SCIENCE, INC.
 Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER PES-mw-15
 JOB NUMBER 722450.18 INSTALLATION DATE 5/18/96 LOCATION Building 1212
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL 20-40 SAND ES REPRESENTATIVE U.S. Army/Blacker
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Bedinger & Assoc



STABILIZED WATER LEVEL 7.85 FEET
 BELOW DATUM.
 MEASURED ON 17:30 - 5/18/96

MONITORING WELL INSTALLATION RECORD

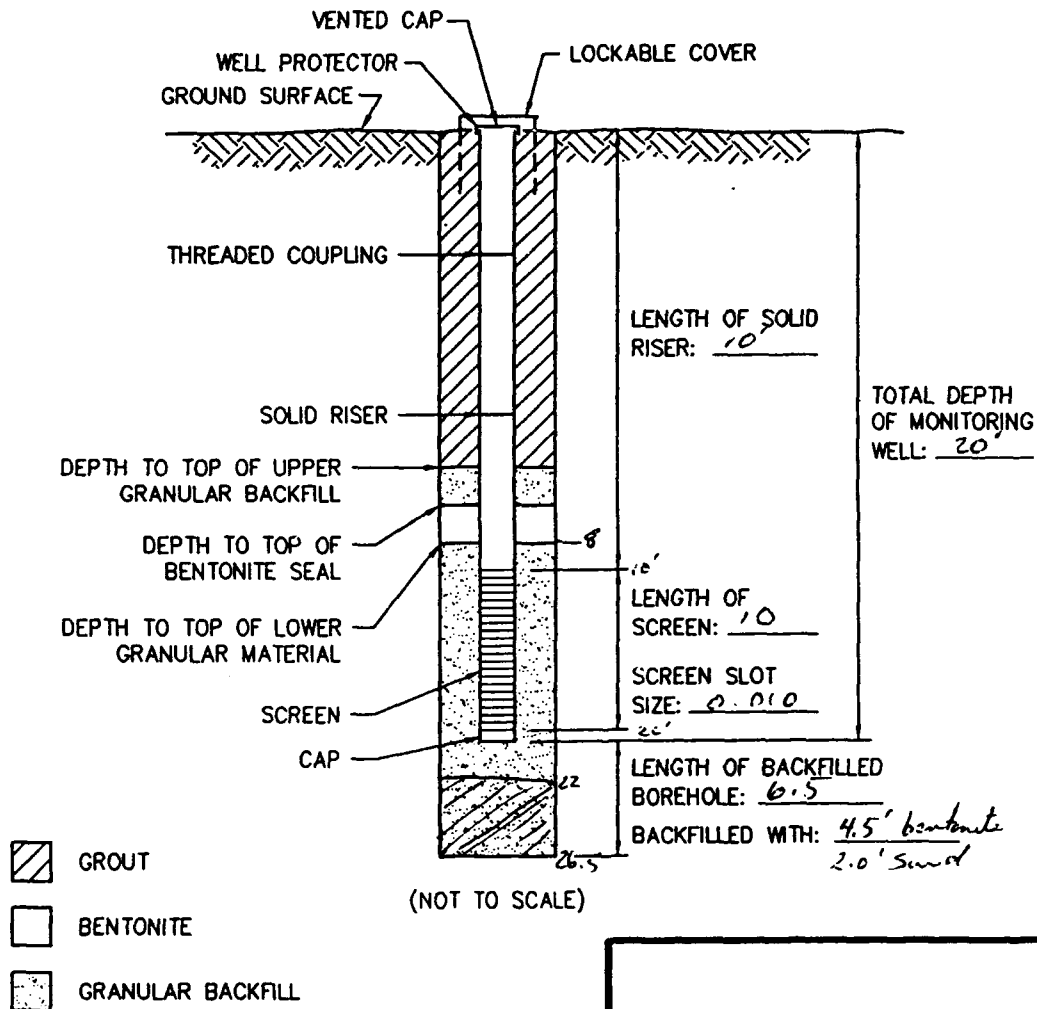
Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER PES-mw-2
 JOB NUMBER 722450.18 INSTALLATION DATE 5/13/96 LOCATION Building 1212
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL Bentonite / 20-40 Sand ES REPRESENTATIVE Hessley / Nichols
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Biedinger & Assoc.



STABILIZED WATER LEVEL 13.3 FEET
 BELOW DATUM.
 MEASURED ON 5/13/96

MONITORING WELL INSTALLATION RECORD

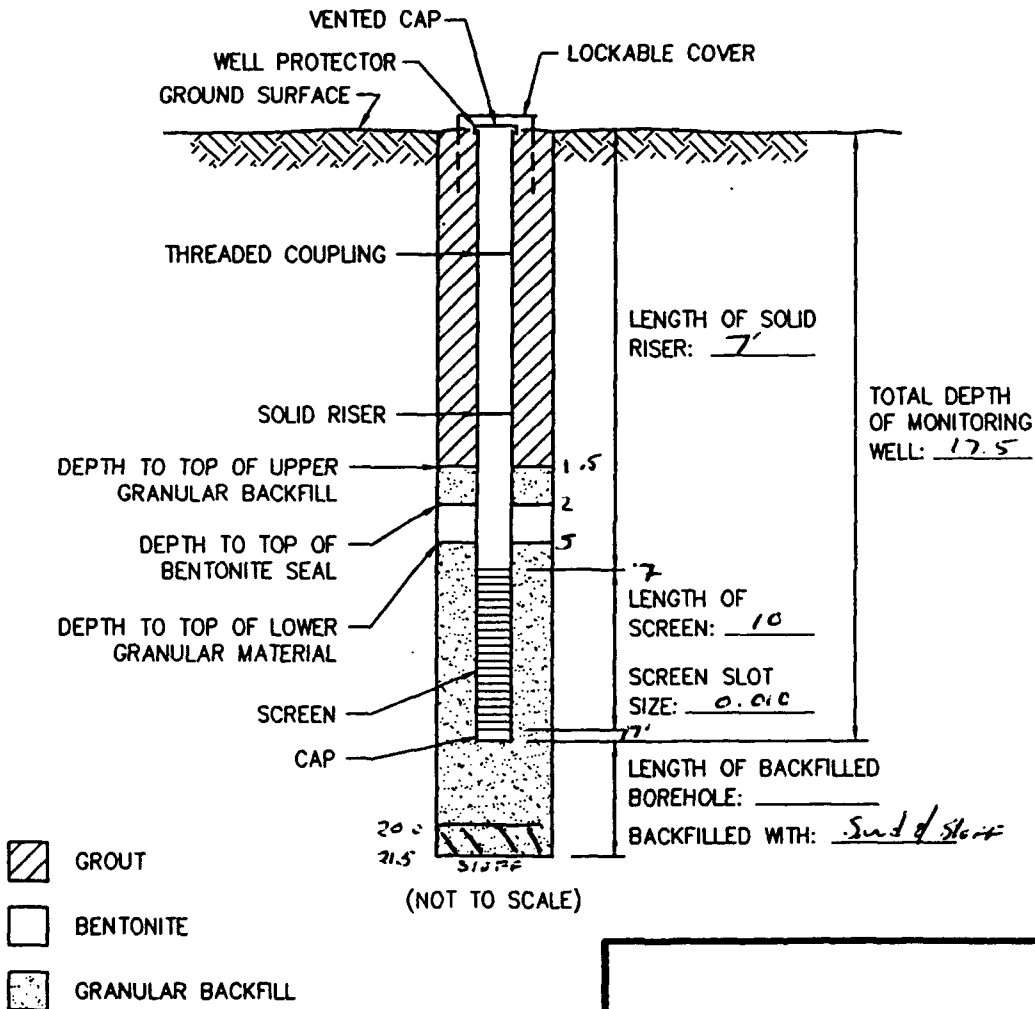
Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER Yes m113
 JOB NUMBER 722450.18 INSTALLATION DATE 5/20/96 LOCATION Bldg 122
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL SAND & SILT (#20-40) ES REPRESENTATIVE Yes
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Budinger Inc.



STABILIZED WATER LEVEL _____ FEET
BELOW DATUM.
MEASURED ON _____

MONITORING WELL INSTALLATION RECORD

Building 1212 TS
Remediation by Natural Attenuation
Fairchild AFB, Washington

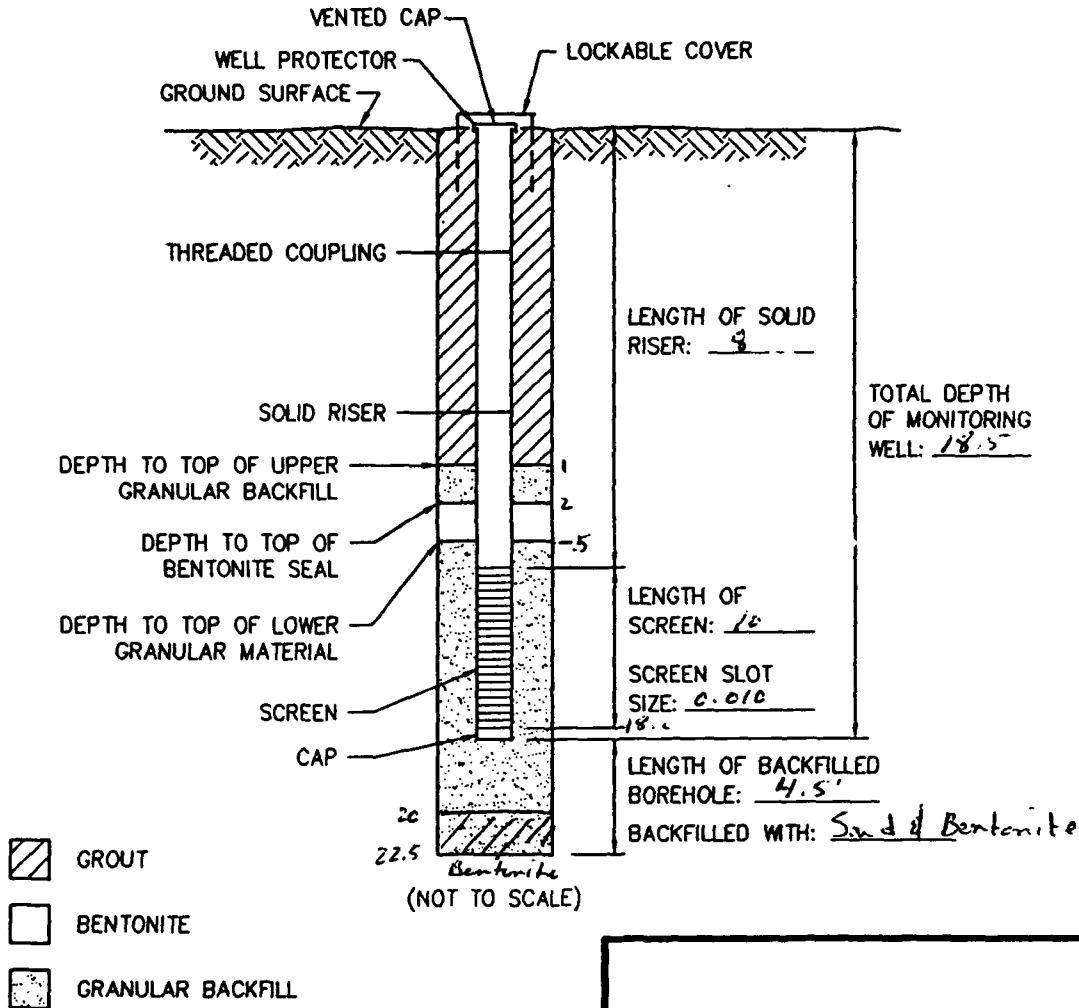


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MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER FE5-MW-4
JOB NUMBER 722450.18 INSTALLATION DATE 5/20/96 LOCATION Bld 1212
DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
DATUM FOR WATER LEVEL MEASUREMENT _____
SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
GRANULAR BACKFILL MATERIAL SAND & G. Mtl (20-40) REPRESENTATIVE Vessely
DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Budinger / Assoc.



STABILIZED WATER LEVEL _____ FEET
BELOW DATUM.
MEASURED ON _____

MONITORING WELL INSTALLATION RECORD

**Building 1212 TS
Remediation by Natural Attenuation
Fairchild AFB, Washington**

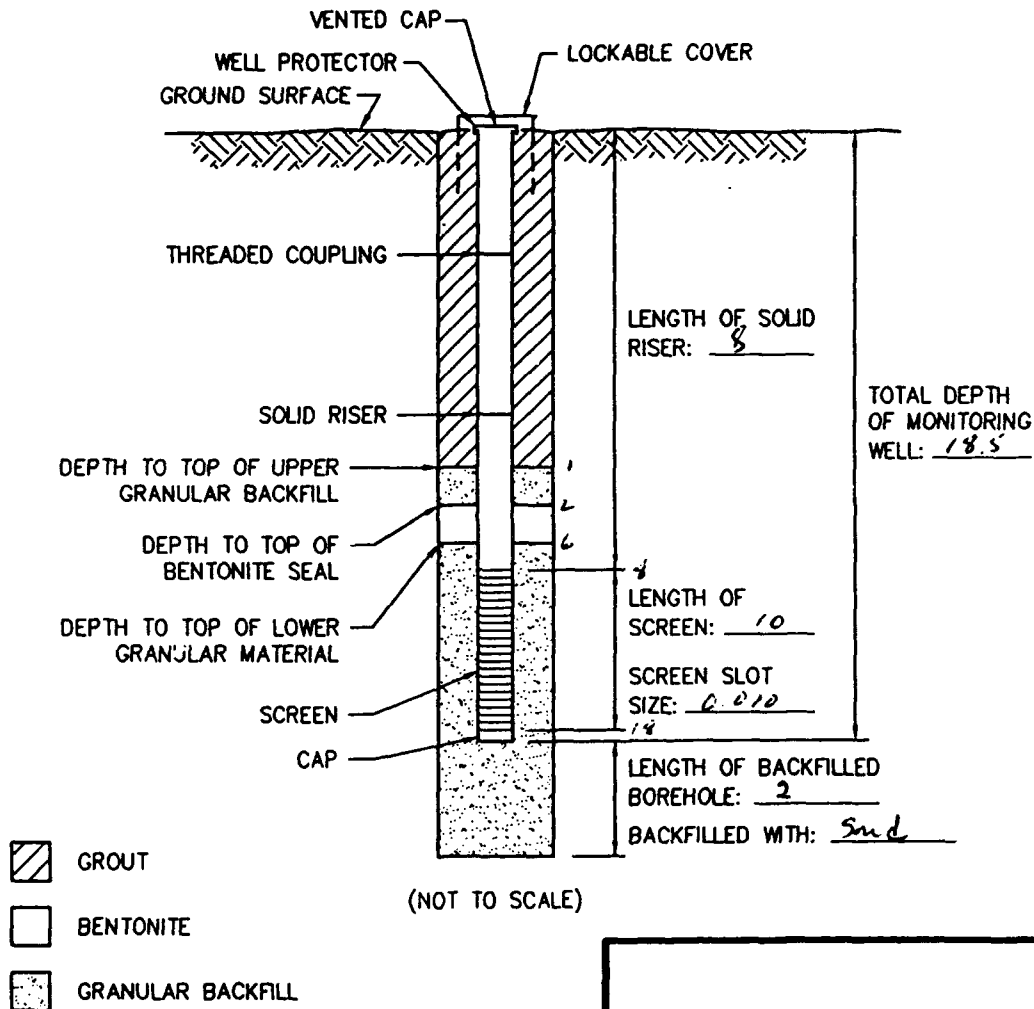


**PARSONS
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Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER PES-MW-5
 JOB NUMBER 722450.18 INSTALLATION DATE 5/20/96 LOCATION Building 1212
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL 20-40 SAND ES REPRESENTATIVE VESSELY
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Budinger Assoc.



STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.
 MEASURED ON _____

MONITORING WELL INSTALLATION RECORD

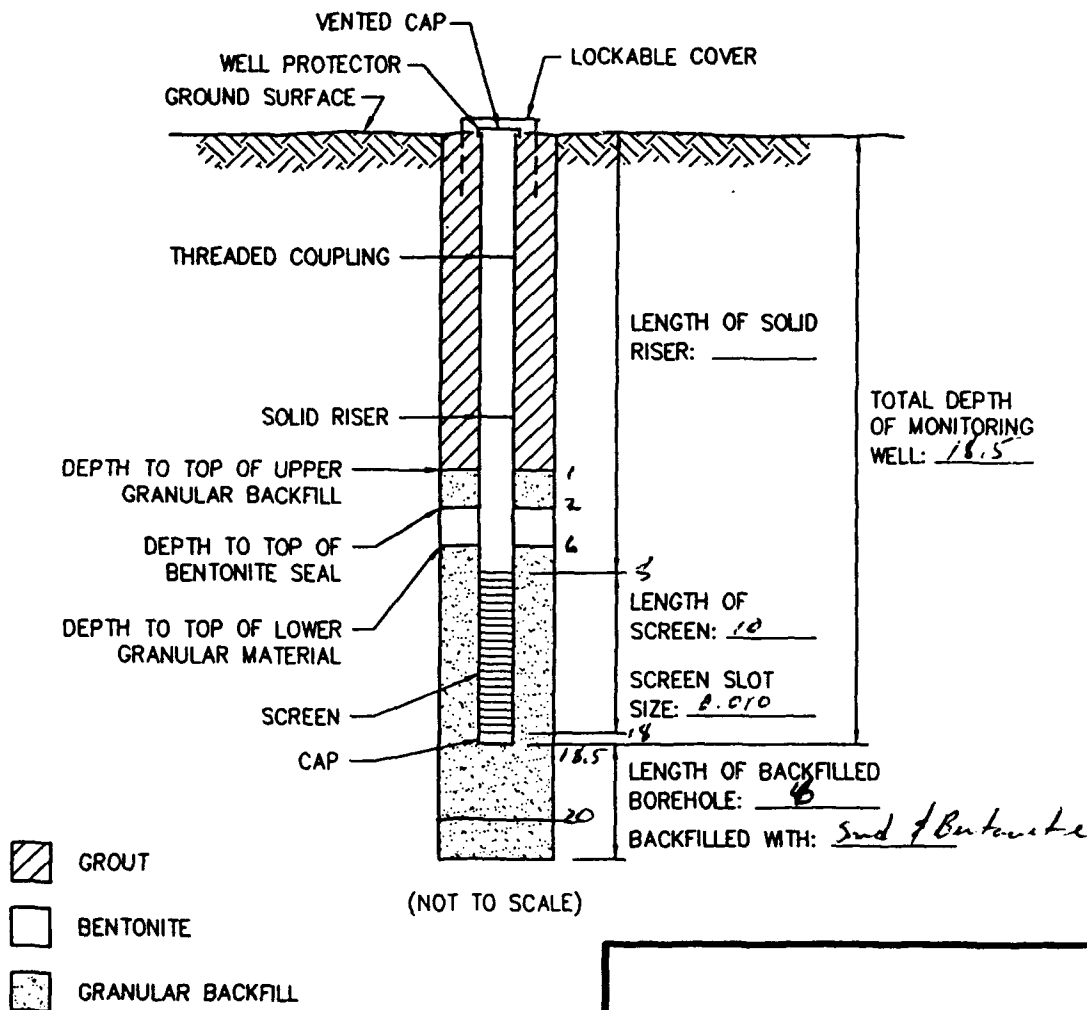
Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER MW-6
 JOB NUMBER 722450.18 INSTALLATION DATE 5/20/96 LOCATION _____
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL Sand & Bentonite ES REPRESENTATIVE V. usely
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Bedinger & Assoc



STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.
 MEASURED ON _____

MONITORING WELL INSTALLATION RECORD

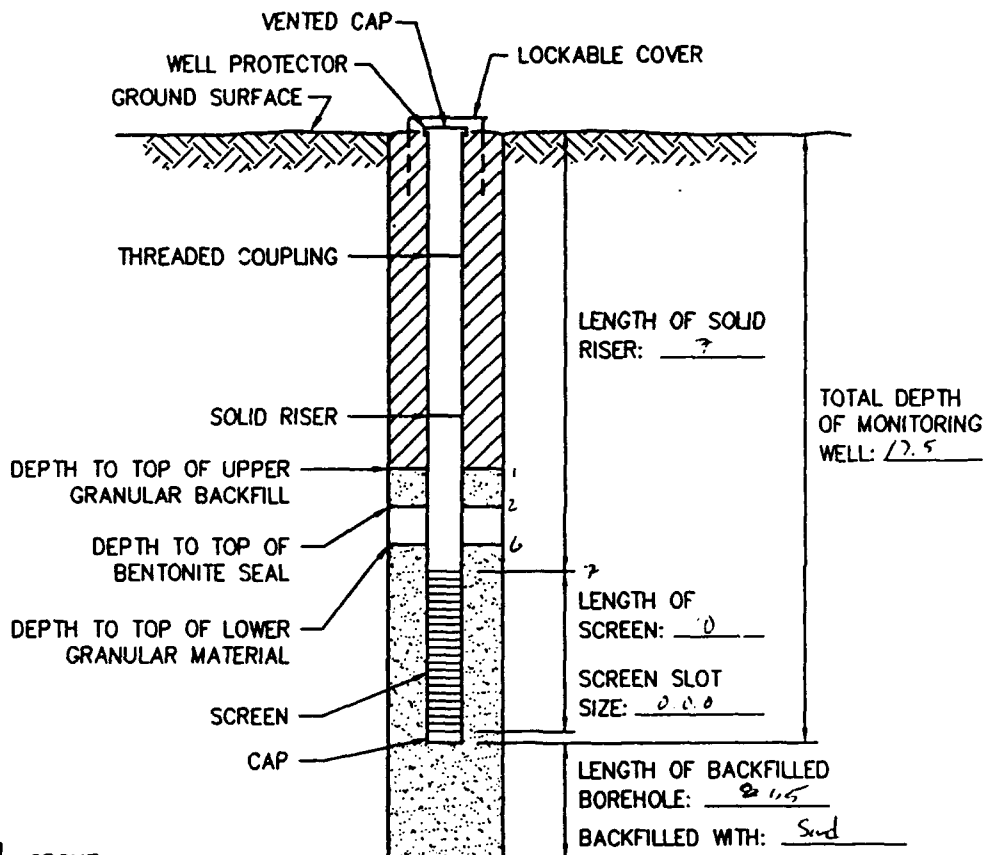
Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington




**PARSONS
 ENGINEERING SCIENCE, INC.**

Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER mw-7
 JOB NUMBER 722450.18 INSTALLATION DATE 5/21/96 LOCATION _____
 DATUM ELEVATION 2432.30 GROUND SURFACE ELEVATION 2432.69
 DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL SAND # 20-40 ES REPRESENTATIVE Vesely
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Budinger & Assoc.



-  **GROUT**
-  **BENTONITE**
-  **GRANULAR BACKFILL**

(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.
 MEASURED ON _____

MONITORING WELL INSTALLATION RECORD

Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

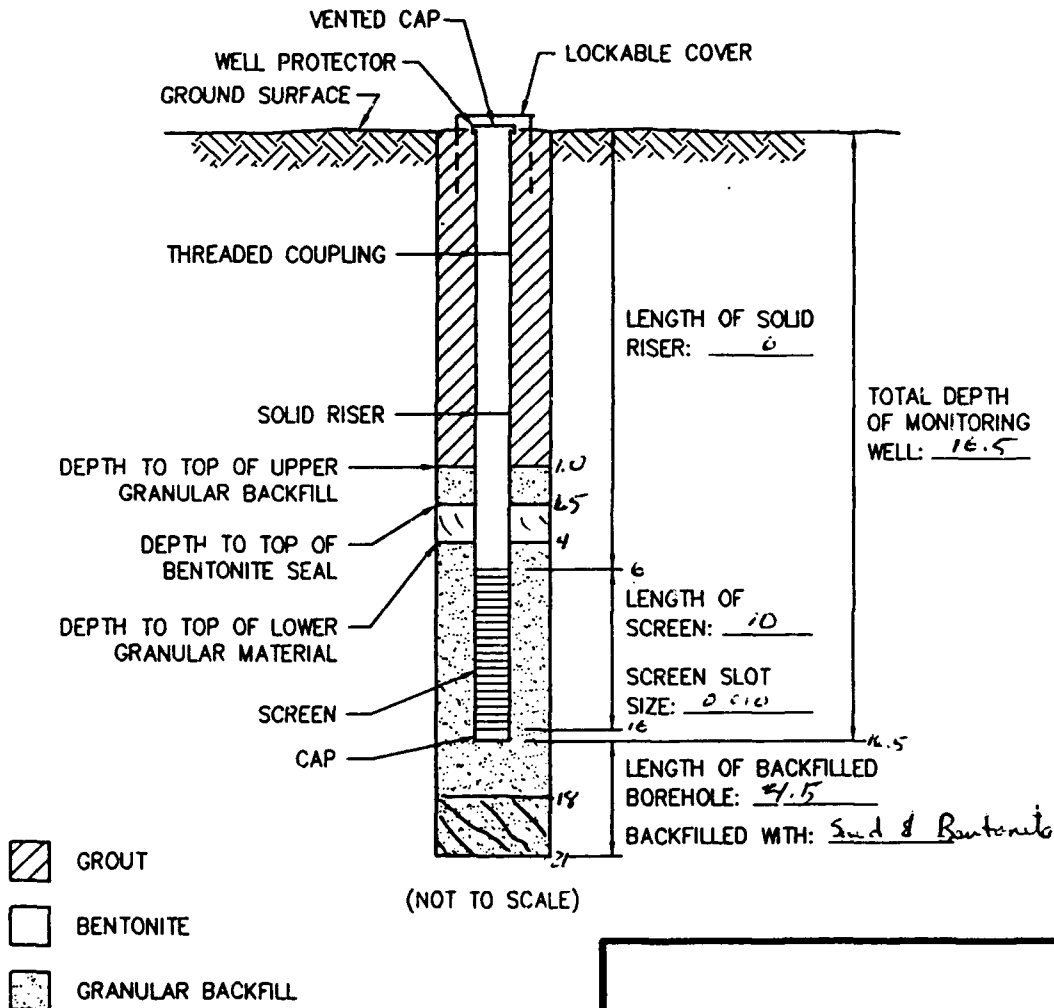


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Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER MW-8
 JOB NUMBER 722450.18 INSTALLATION DATE 5/21/96 LOCATION Building 1212
 DATUM ELEVATION 2431.70 GROUND SURFACE ELEVATION 2431.97
 DATUM FOR WATER LEVEL MEASUREMENT Top of Casing
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL Sand & Bentonite (20-40) ES REPRESENTATIVE Vessely
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Budinger & Assoc.



STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.
 MEASURED ON _____

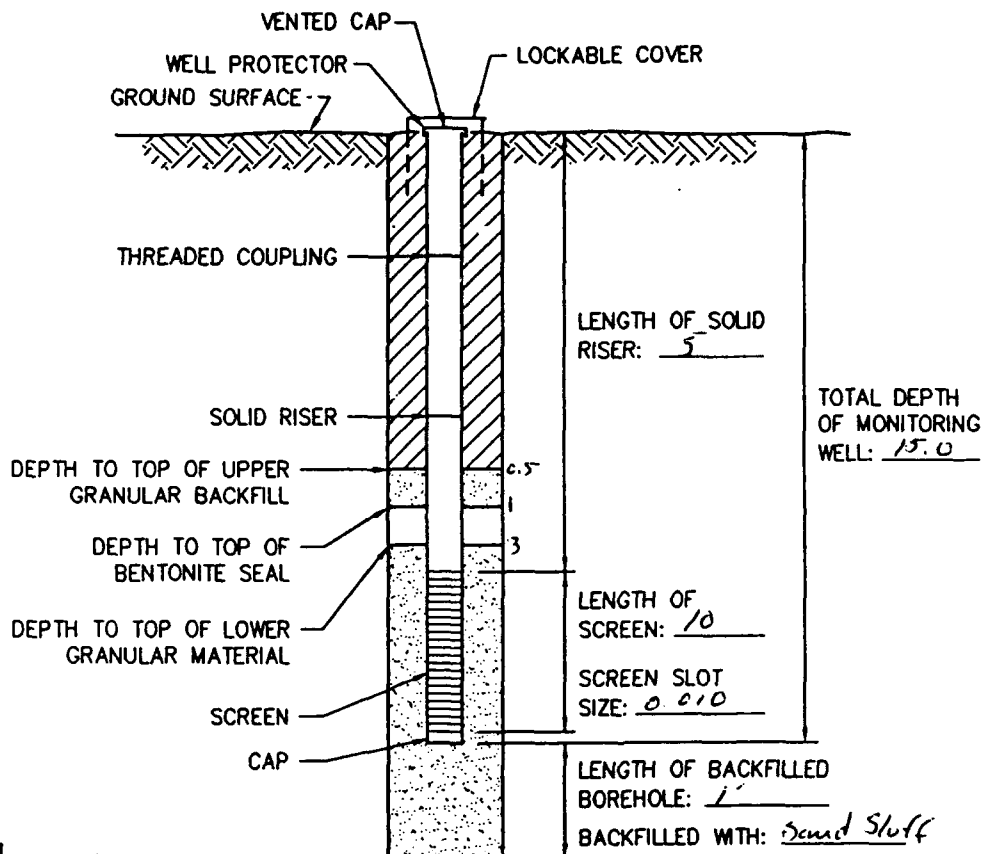
MONITORING WELL INSTALLATION RECORD

Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

PARSONS
ENGINEERING SCIENCE, INC.
 Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER MW-9
 JOB NUMBER 722450.18 INSTALLATION DATE 5/21/96 LOCATION Building 1212
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT Top of casing
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL SAND & Gravel (20-40) ES REPRESENTATIVE Vessel
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Budget Assoc



- ☒ GROUT
- ☐ BENTONITE
- ☐ GRANULAR BACKFILL

(NOT TO SCALE)

STABILIZED WATER LEVEL 6.86 FEET
 BELOW DATUM.
 MEASURED ON 5/22/96

MONITORING WELL INSTALLATION RECORD

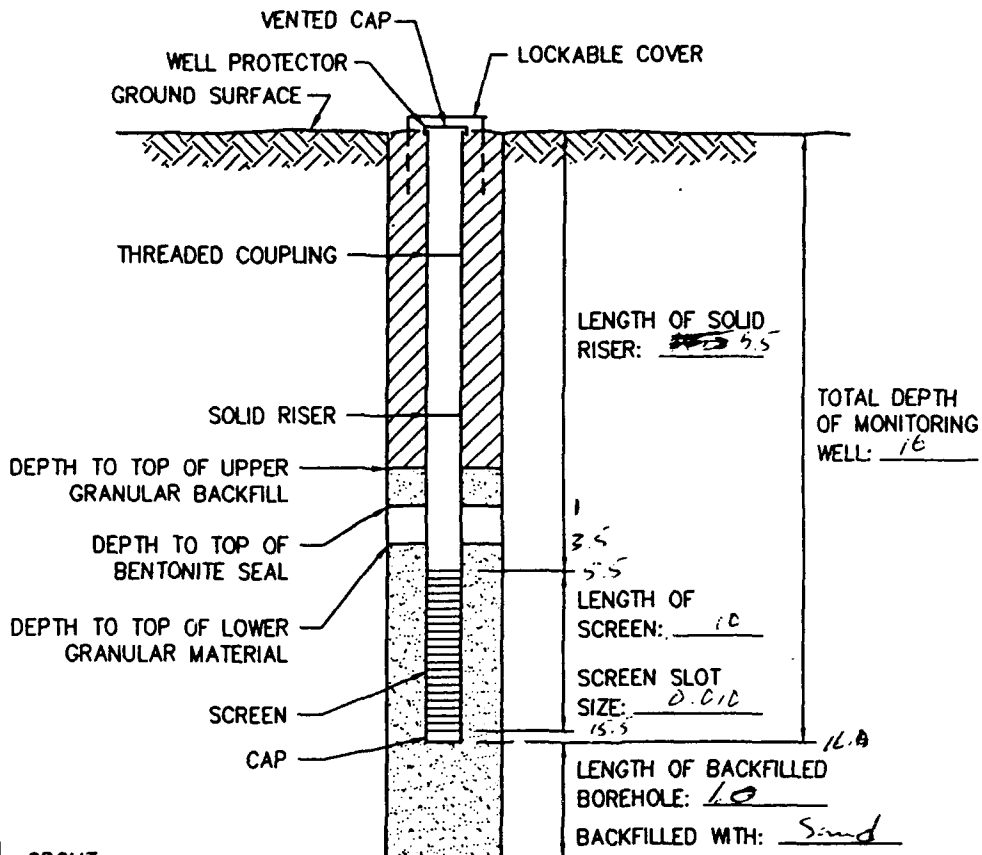
Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

**PARSONS
 ENGINEERING SCIENCE, INC.**




Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER MCC-10
 JOB NUMBER 722450.18 INSTALLATION DATE 5/21 LOCATION Building 1212
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL Sand & 20/40 ES REPRESENTATIVE Vossler
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Bulmer & Assoc



(NOT TO SCALE)

-  GROUT
-  BENTONITE
-  GRANULAR BACKFILL

STABILIZED WATER LEVEL 5.56 FEET
 BELOW DATUM.
 MEASURED ON 5/22/96

MONITORING WELL INSTALLATION RECORD

Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

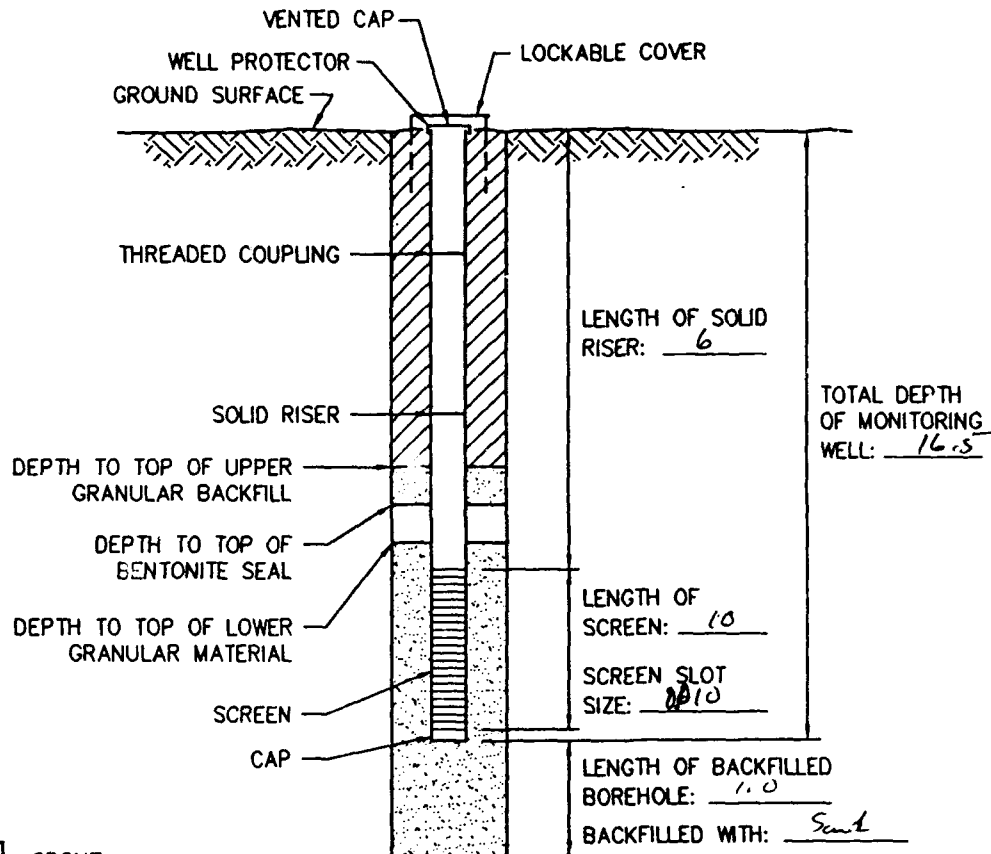


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Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER MW-11
 JOB NUMBER 722450.18 INSTALLATION DATE 5/21/96 LOCATION Bld 1212
 DATUM ELEVATION 2430.36 GROUND SURFACE ELEVATION 2430.65
 DATUM FOR WATER LEVEL MEASUREMENT Top of Casing
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL Sand # 20-40 ES REPRESENTATIVE Vissio
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Budinger Assoc.



(NOT TO SCALE)

STABILIZED WATER LEVEL 5.48 FEET
 BELOW DATUM.
 MEASURED ON 5/22/96

MONITORING WELL INSTALLATION RECORD

Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington

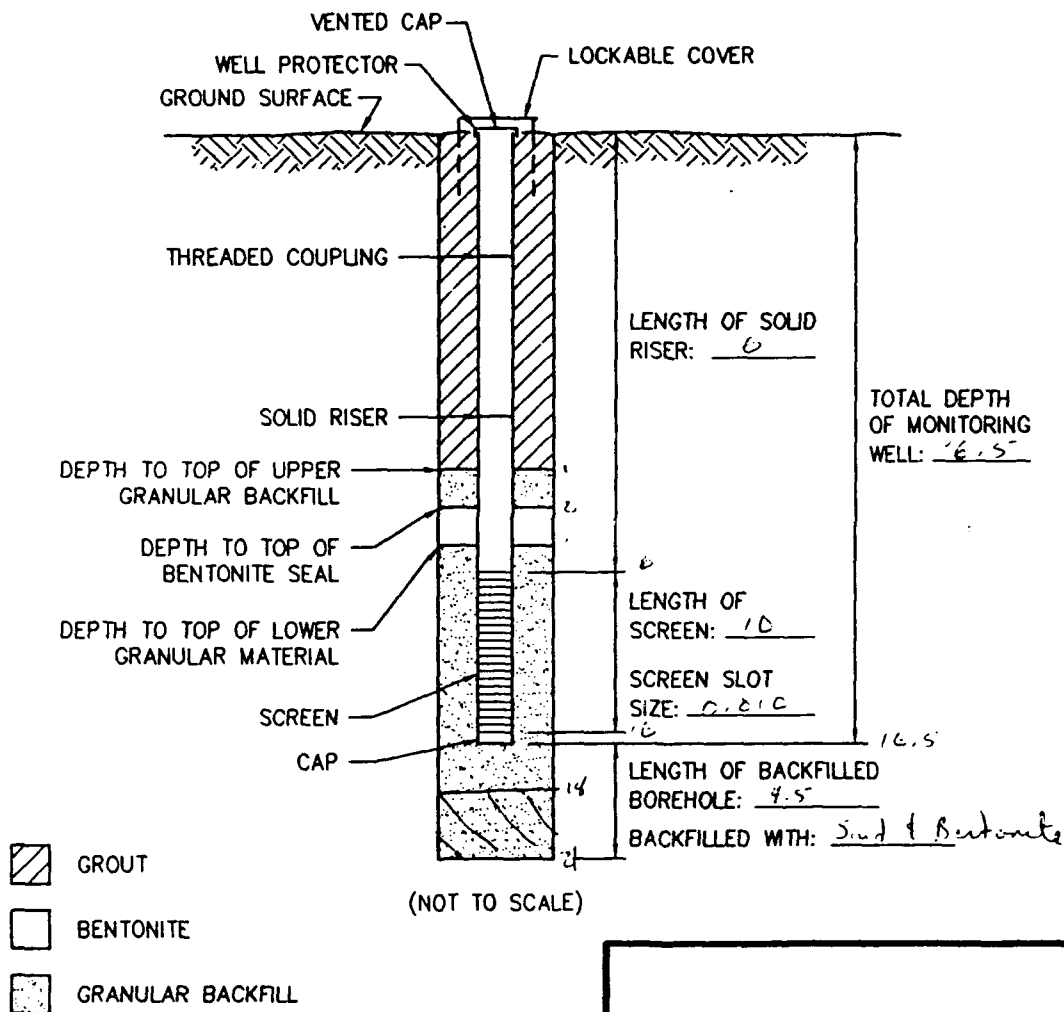


**PARSONS
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Denver, Colorado

MONITORING WELL INSTALLATION RECORD

JOB NAME FAIRCHILD AIR FORCE BASE WELL NUMBER MW-12
 JOB NUMBER 722450.18 INSTALLATION DATE 5/22/96 LOCATION Building
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL Sand 20-40 ES REPRESENTATIVE Vossler
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Bohannon & Assoc.



STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.
 MEASURED ON _____

MONITORING WELL INSTALLATION RECORD

Building 1212 TS
 Remediation by Natural Attenuation
 Fairchild AFB, Washington



**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

APPENDIX A.3

SLUG TEST RESULTS

Bld 1212, MW-3 (Falling Head Test-1)

DATA SET

06/04/96

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bowen-Rice

ESTIMATED PARAMETERS

$K = 0.0007965 \text{ ft/min}$

$V0 = 0.432 \text{ ft}$

TEST DATA

$H0 = 1 \text{ ft}$

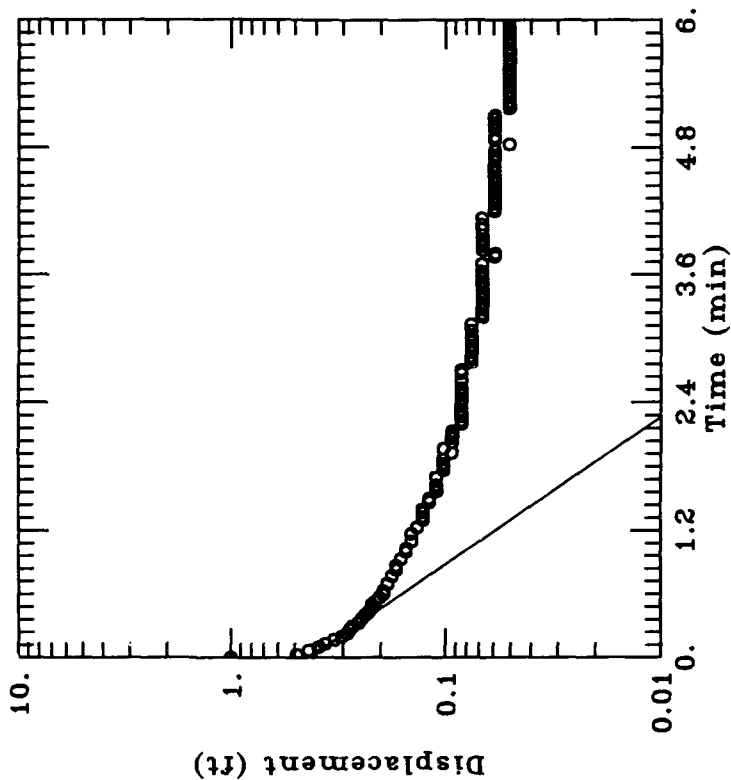
$rc = 0.167 \text{ ft}$

$rw = 0.667 \text{ ft}$

$L = 10 \text{ ft}$

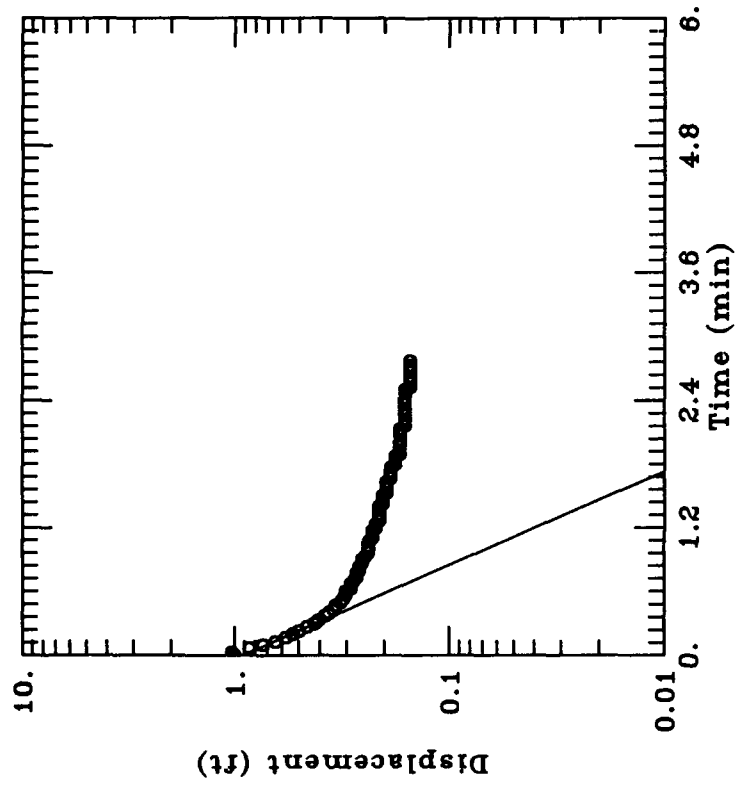
$b = 14 \text{ ft}$

$H = 1 \text{ ft}$



Bld 1212, MW-3 (Falling Head Test-2)

DATA SET	06/04/96
AQUIFER TYPE	Unconfined
SOLUTION METHOD	Bouwer-Rice
ESTIMATED PARAMETERS	<p>K = 0.001252 ft/min</p> <p>Y0 = 0.9172 ft</p>
TEST DATA	<p>H0 = 1 ft</p> <p>rc = 0.167 ft</p> <p>rw = 0.667 ft</p> <p>L = 10 ft</p> <p>P = 14 ft</p> <p>H = 1 ft</p>



Bld 1212, MW-3 (Rising Head Test-1)

DATA SET

06/04/96

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bowen-Rice

ESTIMATED PARAMETERS

$K = 0.001929$ ft/min

$V_0 = 0.9956$ ft

TEST DATA

$H_0 = 1$ ft

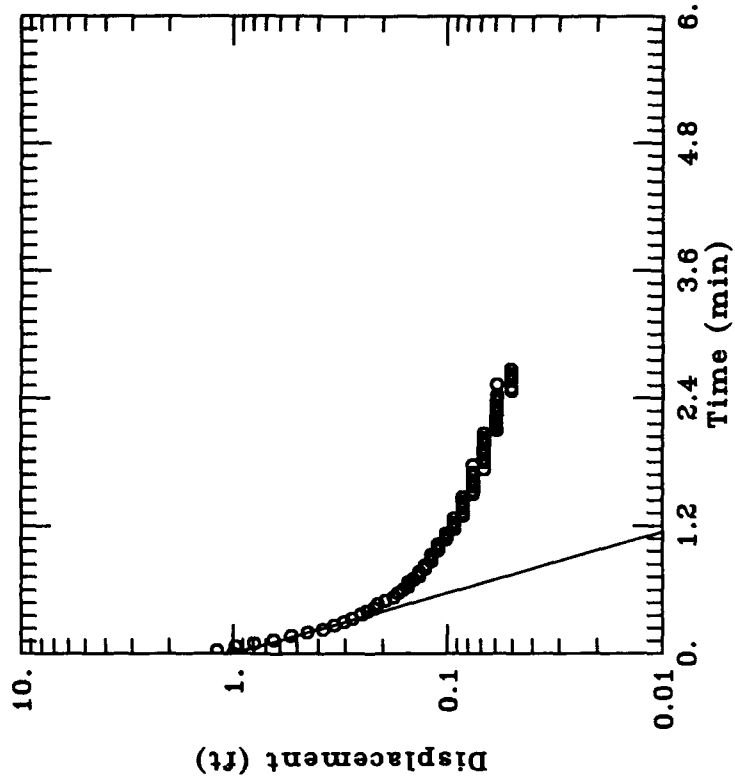
$r_c = 0.167$ ft

$r_w = 0.667$ ft

$L = 10$ ft

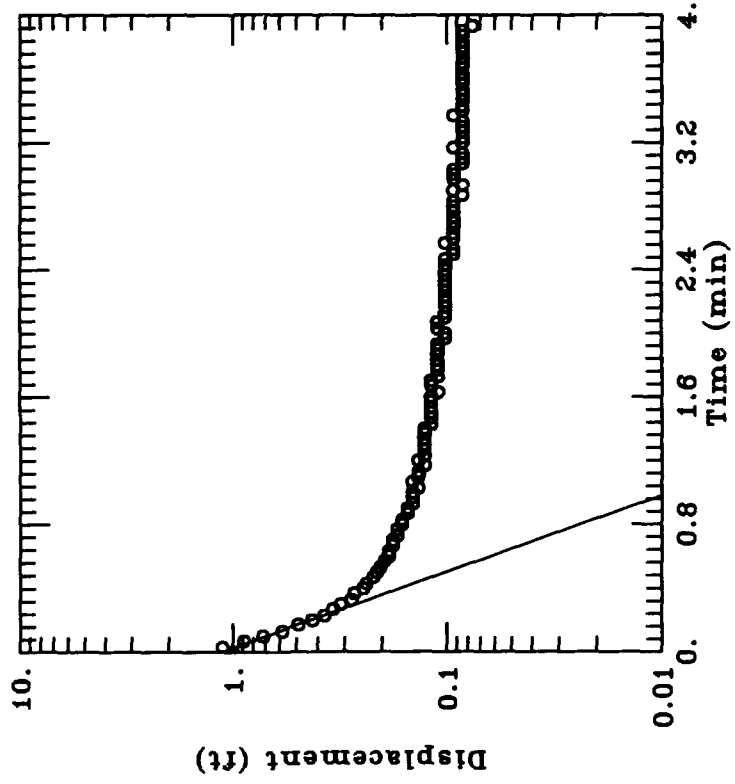
$b = 14$ ft

$H = 1$ ft



Bld 1212, MW-3 (Rising Head Test-2)

DATA SET
06/04/96
AQUIFER TYPE
Unconfined
SOLUTION METHOD
Bouwer-Rice
ESTIMATED PARAMETERS
K = 0.00231 ft/min
Y0 = 1.134 ft
TEST DATA
H0 = 1 ft
rc = 0.167 ft
rw = 0.667 ft
L = 10 ft
b = 14 ft
H = 1 ft



Bld 1212, MW-5 (Falling Head Test-1)

DATA SET

06/04/96

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

$\gamma = 0.0003404 \text{ ft/min}$

$y_0 = 1.513 \text{ ft}$

TEST DATA

$H_0 = 1 \text{ ft}$

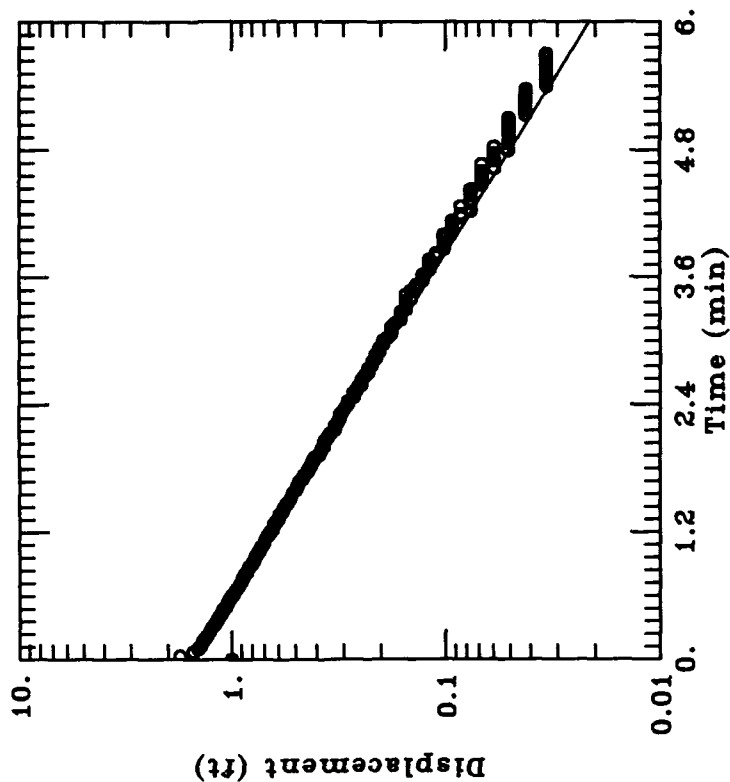
$rc = 0.167 \text{ ft}$

$rw = 0.667 \text{ ft}$

$L = 10 \text{ ft}$

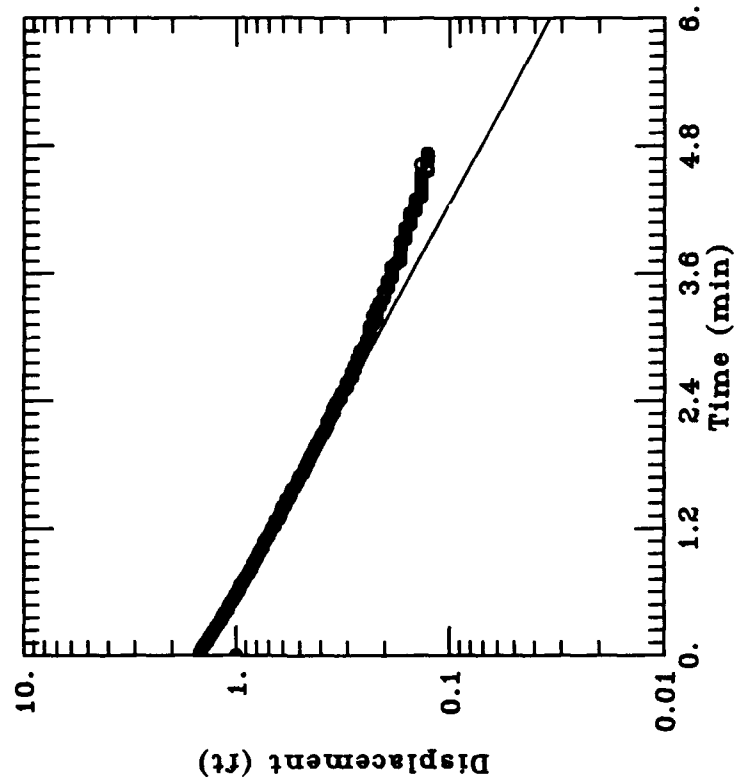
$b = 14 \text{ ft}$

$H = 1 \text{ ft}$



Bld 1212, MW-5 (Falling Head Test-2)

DATA SET
06/04/96
AQUIFER TYPE
Unconfined
SOLUTION METHOD
Bouwer-Rice
ESTIMATED PARAMETERS
K = 0.0002981 ft/min
Y0 = 1.419 ft
TEST DATA
H0 = 1 ft
rc = 0.167 ft
rw = 0.667 ft
L = 10 ft
b = 14 ft
H = 1 ft



Bld 1212, MW-5 (Rising Head Test-1)

DATA SET

06/04/96

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

$K = 0.000151 \text{ ft/min}$

$V_0 = 1.47 \text{ ft}$

TEST DATA

$H_0 = 1 \text{ ft}$

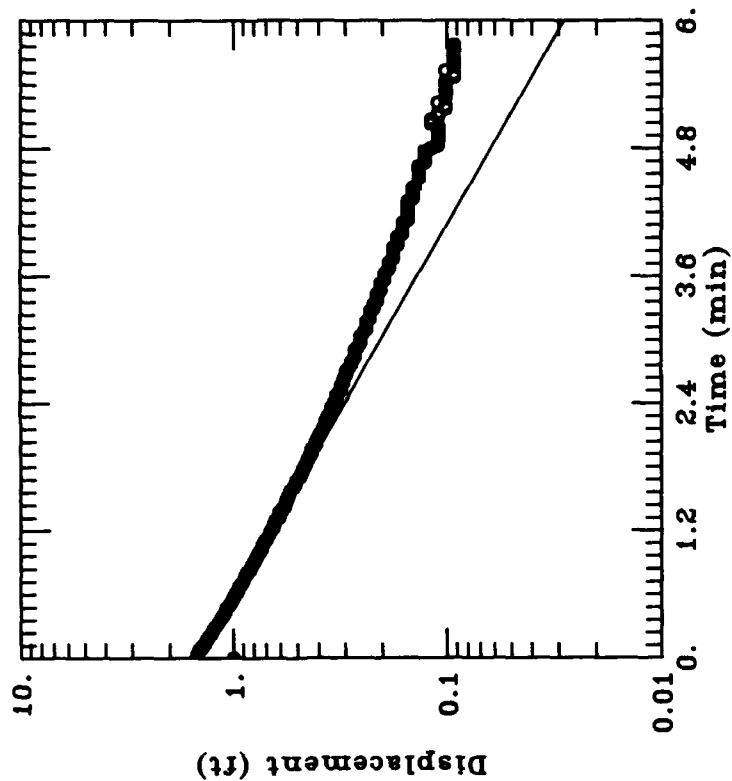
$rc = 0.167 \text{ ft}$

$rw = 0.667 \text{ ft}$

$L = 10 \text{ ft}$

$P = 14 \text{ ft}$

$M = 1 \text{ ft}$



Bld 1212, MW-5 (Rising Head Test-2)

DATA SET

06/04/56

AQUIFER TYPE

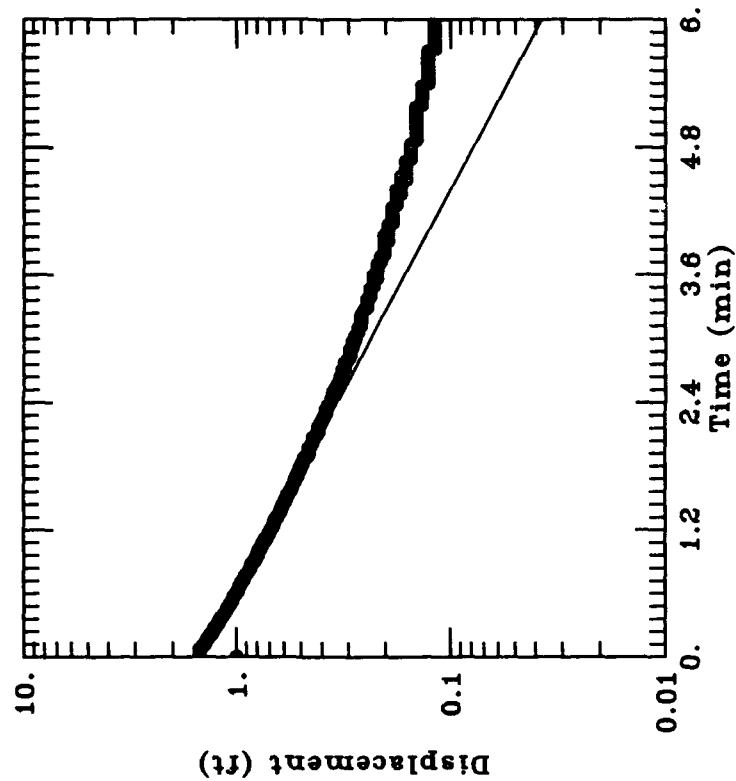
Unconfined
SOLUTION METHOD
Bower-Rice

ESTIMATED PARAMETERS

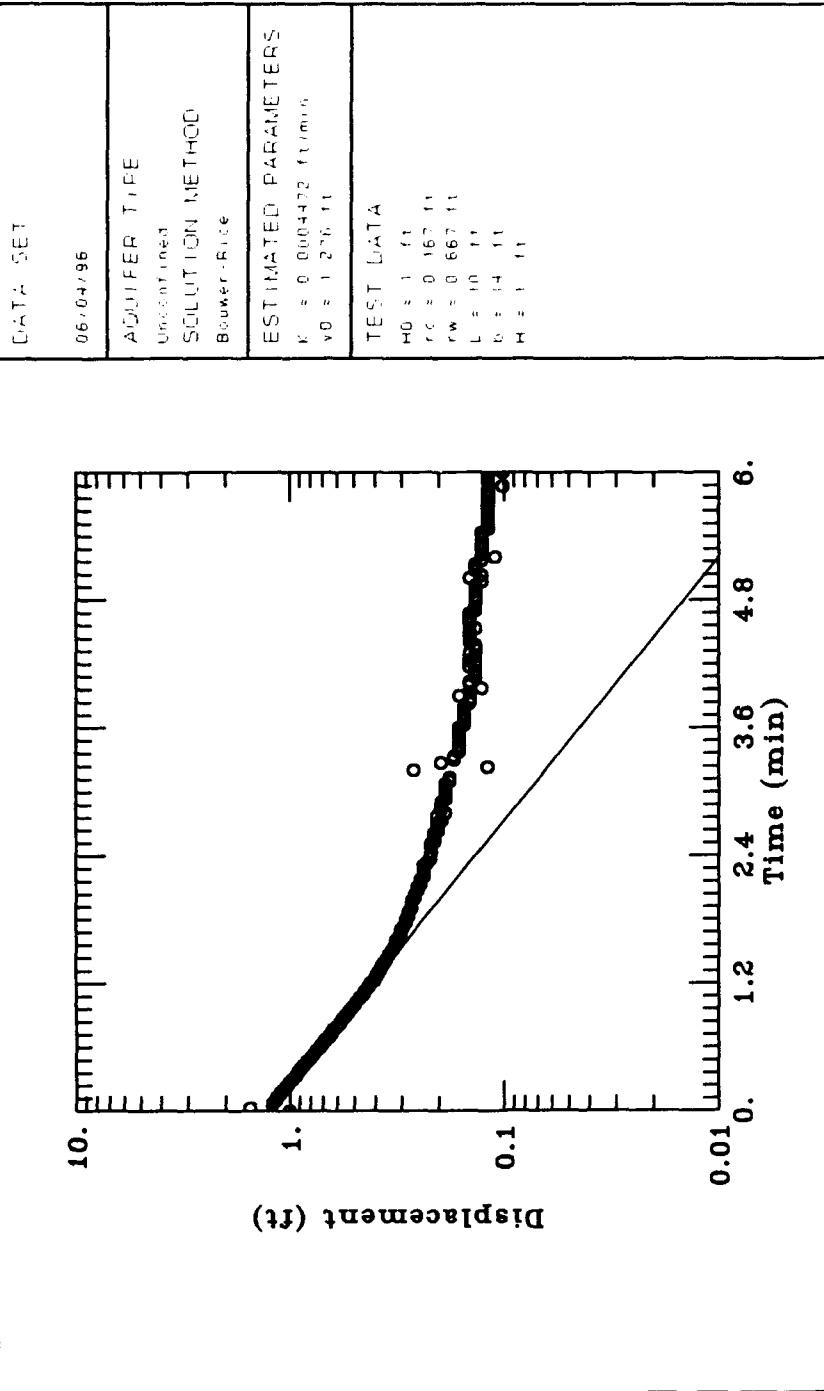
$r = 0.0002931$ ft/min
 $W = 1.479$ ft

TEST DATA

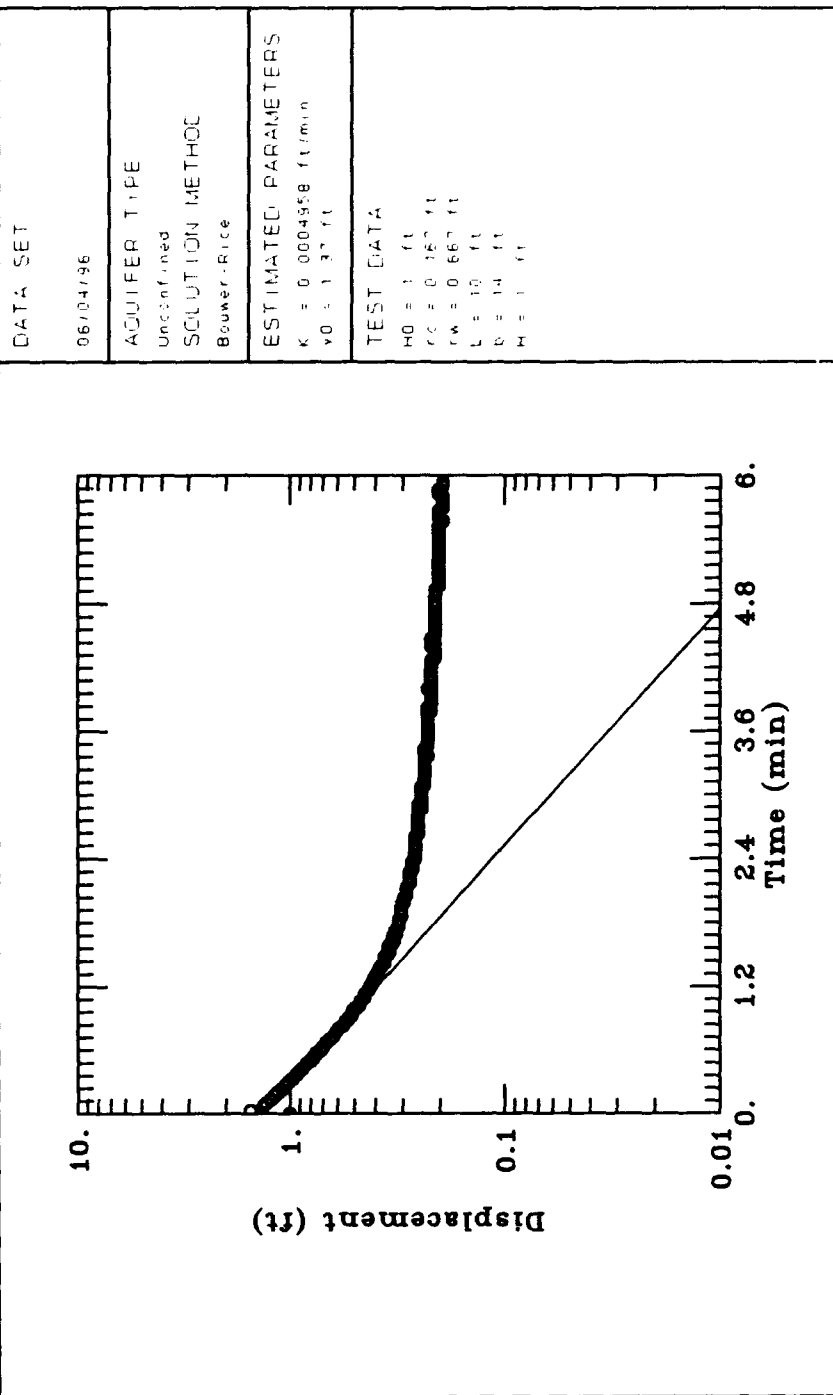
$H_0 = 1$ ft
 $r_0 = 0.167$ ft
 $r_w = 0.667$ ft
 $L = 10$ ft
 $t = 14$ ft
 $H = 1$ ft



Bld 1212, MW-6 (Falling Head Test-1)



Bld 1212, MW-6 (Falling Head Test-2)



Bld 1212, MW-6 (Rising Head Test-1)

DATA SET

06/04/96

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

$k = 0.0005429 \text{ ft/min}$

$kD = 1.339 \text{ ft}^2/\text{min}$

TEST DATA

$H_0 = 1 \text{ ft}$

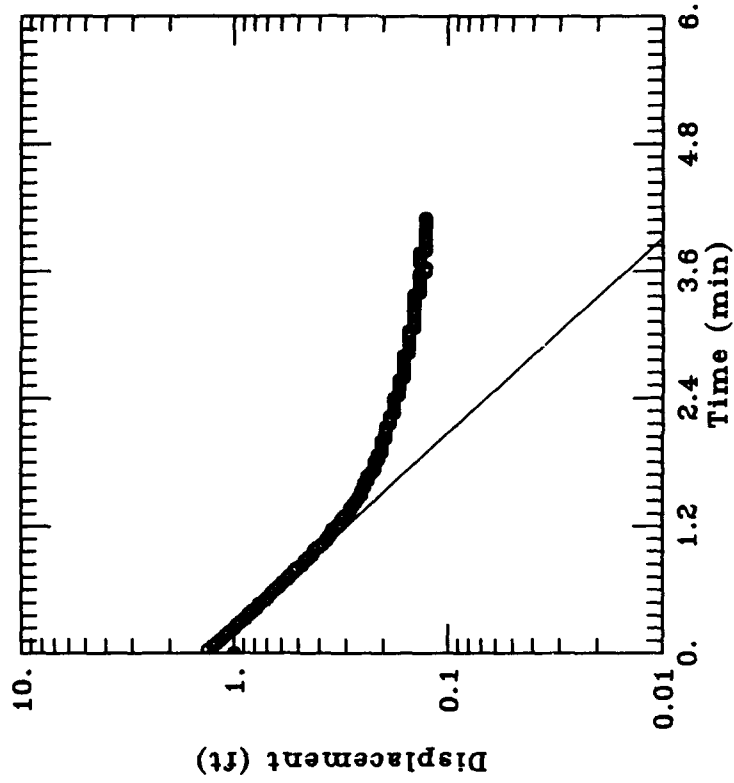
$r_0 = 0.167 \text{ ft}$

$rw = 0.667 \text{ ft}$

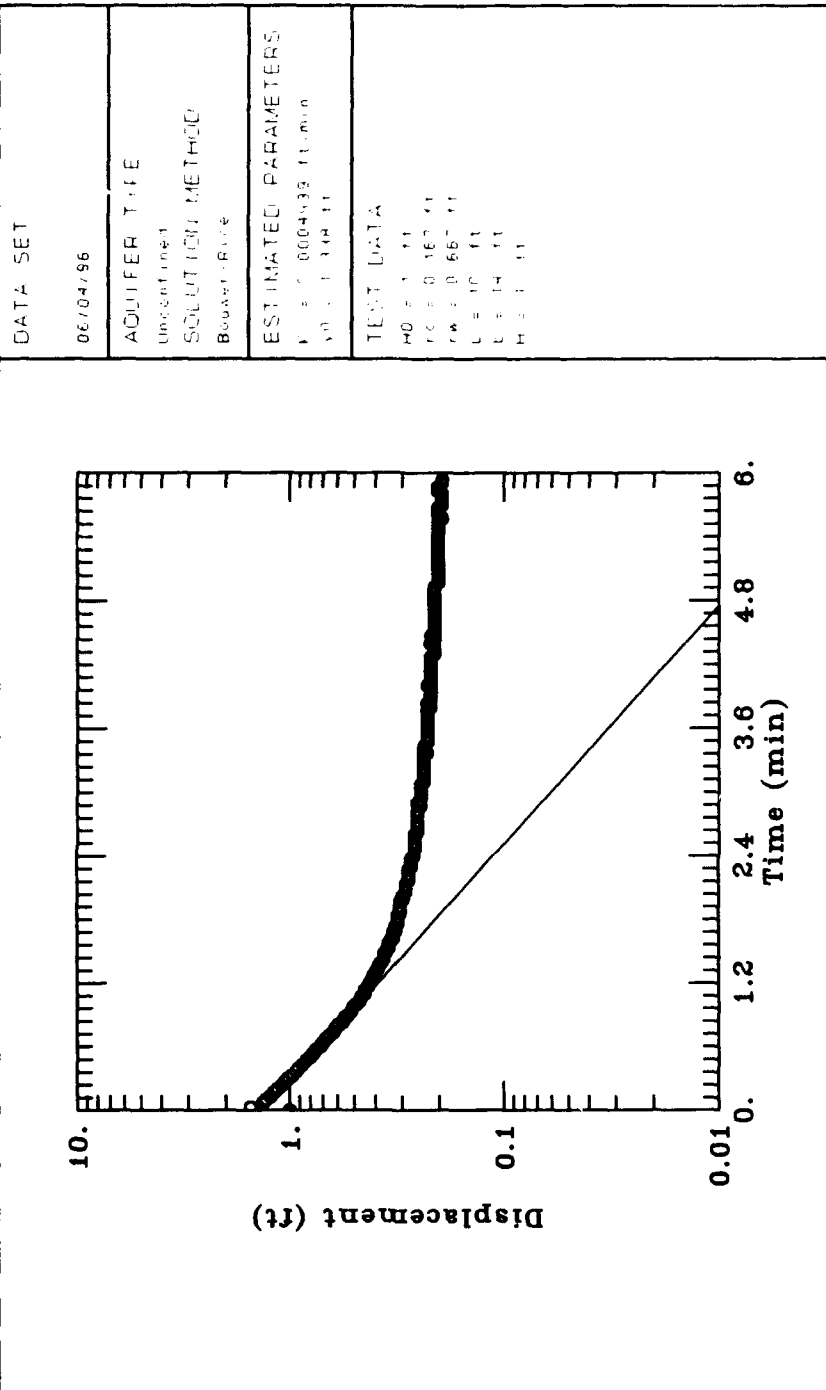
$L = 10 \text{ ft}$

$b = 14 \text{ ft}$

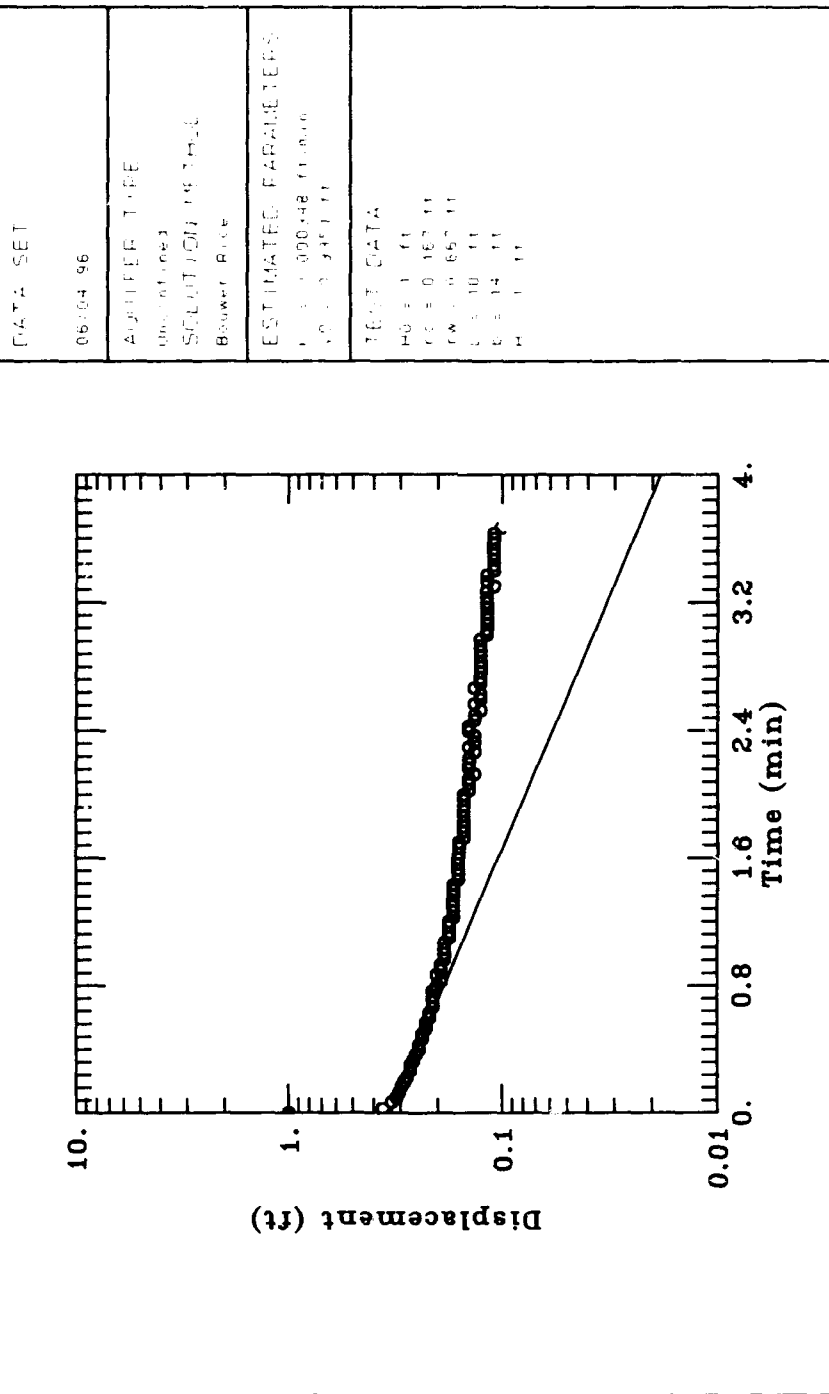
$M = 1 \text{ ft}$



Bld 1212, MW-6 (Rising Head Test-2)



Bld 1212, MW-7 (Falling Head Test-1)



Bld 1212, MW-7 (Falling Head Test-2)

DATA SET

06/04/96

AQUIFER TYPE

Unconsolidated

SOLUTION METHOD

Boussinesq

ESTIMATED PARAMETERS

$\lambda = 0.0003507 \text{ ft min}^{-1}$

$\nu_0 = 0.5324 \text{ ft}$

TEST DATA

$H_0 = 1.11 \text{ ft}$

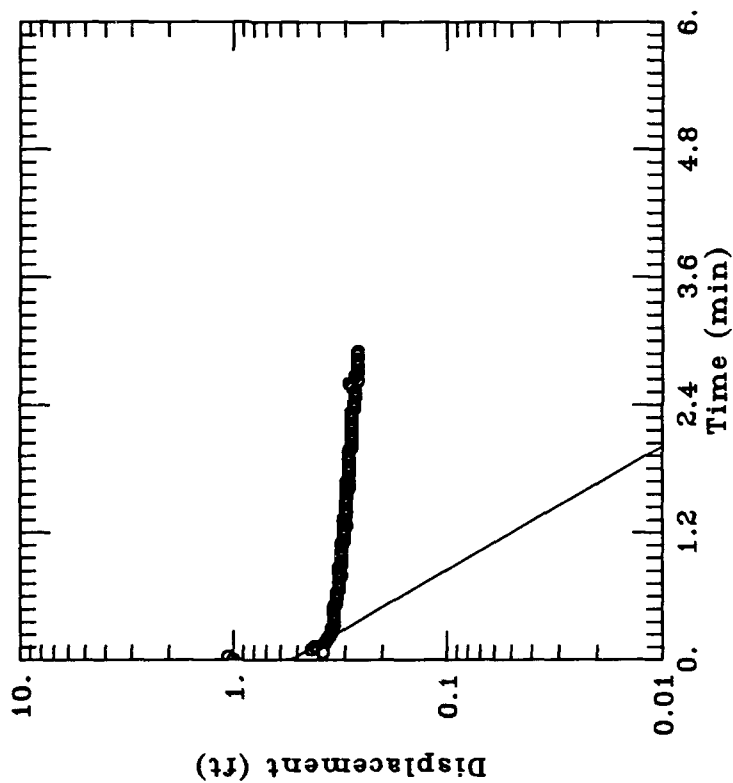
$W = 0.167 \text{ ft}$

$W_0 = 0.667 \text{ ft}$

$Q = 10 \text{ ft}^3/\text{min}$

$W = 14 \text{ ft}$

$H = 1.11 \text{ ft}$



Bld 1212, MW-7 (Rising Head Test-1)

DATA SET

06/04/96

ADAPTER TYPE

Uncoloured

SOLUTION METHOD

Booster Pump

ESTIMATED PARAMETERS

$V = 0.0006326 \text{ ft}^3/\text{min}$

$V_0 = 0.0008 \text{ ft}^3$

TEST DATA

$H_0 = 1.11$

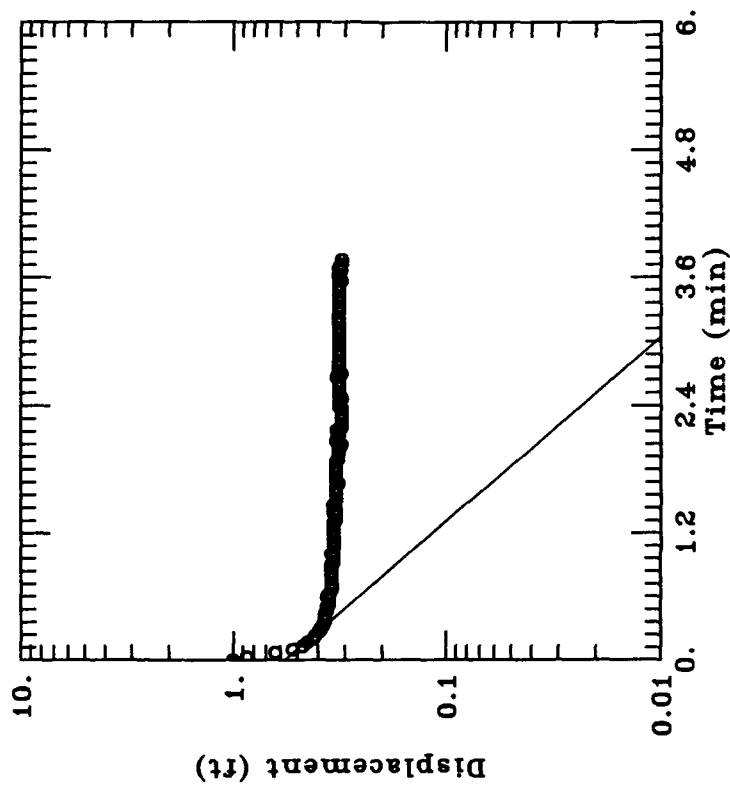
$RC = 0.167 \text{ ft}$

$LV = 0.667 \text{ ft}$

$L = 10.11$

$b = 14.11$

$n = 1.11$



Bld 1212, MW-7 (Rising Head Test-2)

DATA SET

06/04/96

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

$K = 0.0097 \text{ ft/min}$

$\lambda_0 = 0.6093 \text{ ft}$

TEST DATA

$H_0 = 1 \text{ ft}$

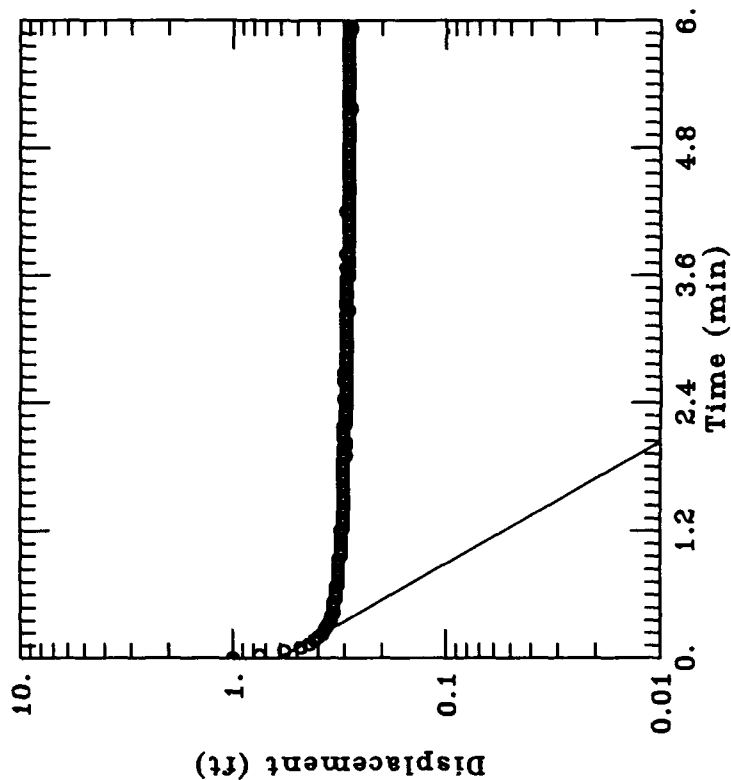
$r_0 = 0.167 \text{ ft}$

$r_w = 0.667 \text{ ft}$

$L = 10 \text{ ft}$

$b = 14 \text{ ft}$

$H = 1 \text{ ft}$



MW-10, Building 1212, Fairchild AFB

FALLING HEAD TEST -1

DATA SET

06103196

ACQUIFER TYPE

Unconfined

SOLUTION METHOD

Brown-Rice

ESTIMATED PARAMETERS

$K = 0.0004852 \text{ ft/min}$

$VQ = 1.259 \text{ ft}$

TEST DATA

$H_0 = 1 \text{ ft}$

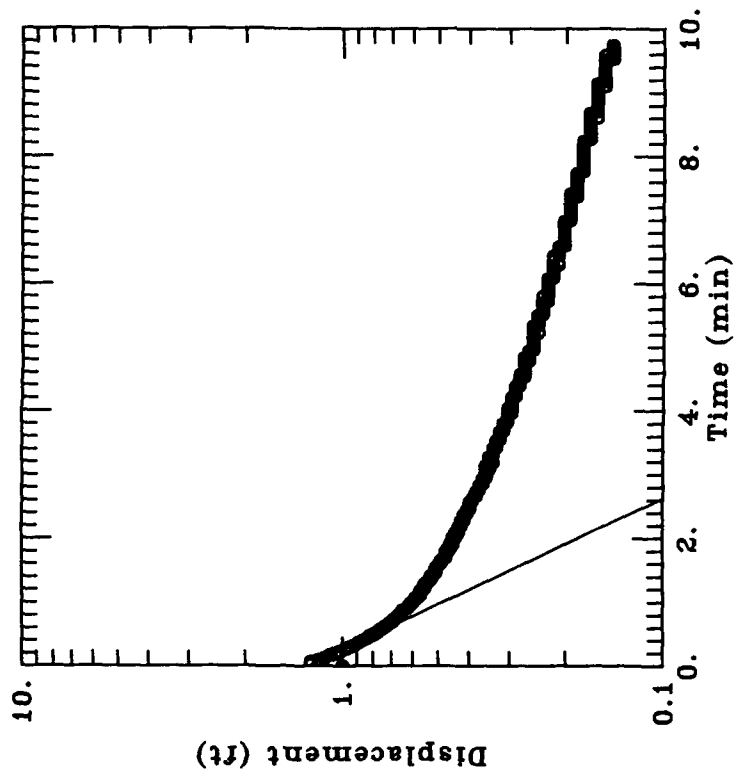
$FS = 0.167 \text{ ft}$

$FW = 0.667 \text{ ft}$

$L = 10 \text{ ft}$

$P = 14 \text{ ft}$

$H = 1 \text{ ft}$



Bld 1212, MW-10 (Falling Head Test-2)

DATA SET

06/04/96

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

$K = 0.0003201 \text{ ft/min}$

$\lambda D = 1.097 \text{ ft}$

TEST DATA

$H_0 = 1 \text{ ft}$

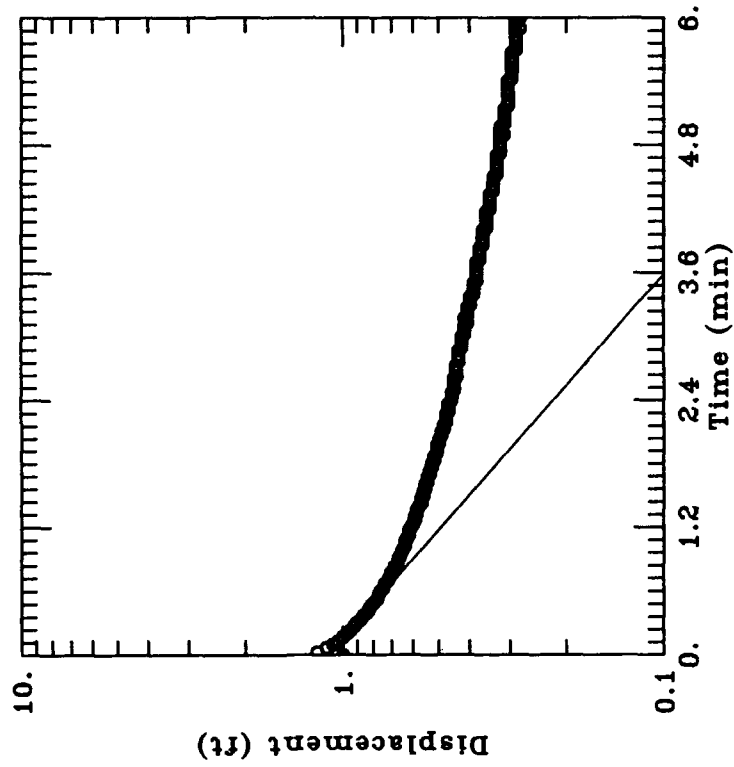
$r/e = 0.167 \text{ ft}$

$r_w = 0.667 \text{ ft}$

$L = 10 \text{ ft}$

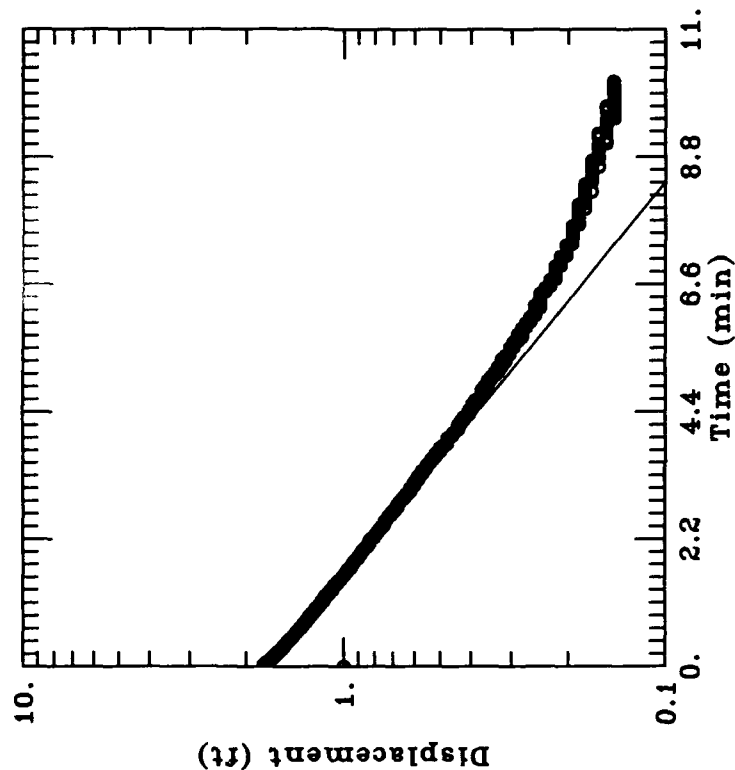
$b = 14 \text{ ft}$

$H = 1 \text{ ft}$



MW-10, Building 1212, Fairchild AFB, WA

Rising Head TEST-1



DATA SET

06:04:56

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bowen-Rice

ESTIMATED PARAMETERS

$K = 0.00018 \text{ ft/min}$

$Y0 = 1.015 \text{ ft}$

TEST DATA

$H0 = 1 \text{ ft}$

$Y0 = 0.157 \text{ ft}$

$Y0 = 0.662 \text{ ft}$

$L = 10 \text{ ft}$

$Z = 14 \text{ ft}$

$H = 1 \text{ ft}$

Bld 1212, MW-10 (Rising Head Test-2)

DATA SET

06/04/96

ADAPTER TYPE

06/04/96

SOLUTION METHOD

06/04/96

ESTIMATED PARAMETERS

06/04/96

TEST DATA

06/04/96

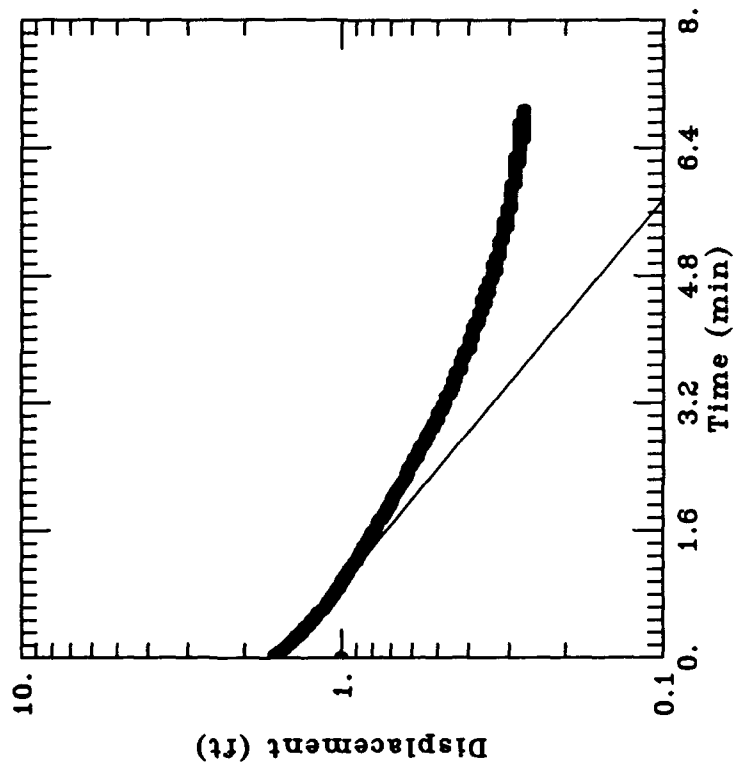
06/04/96

06/04/96

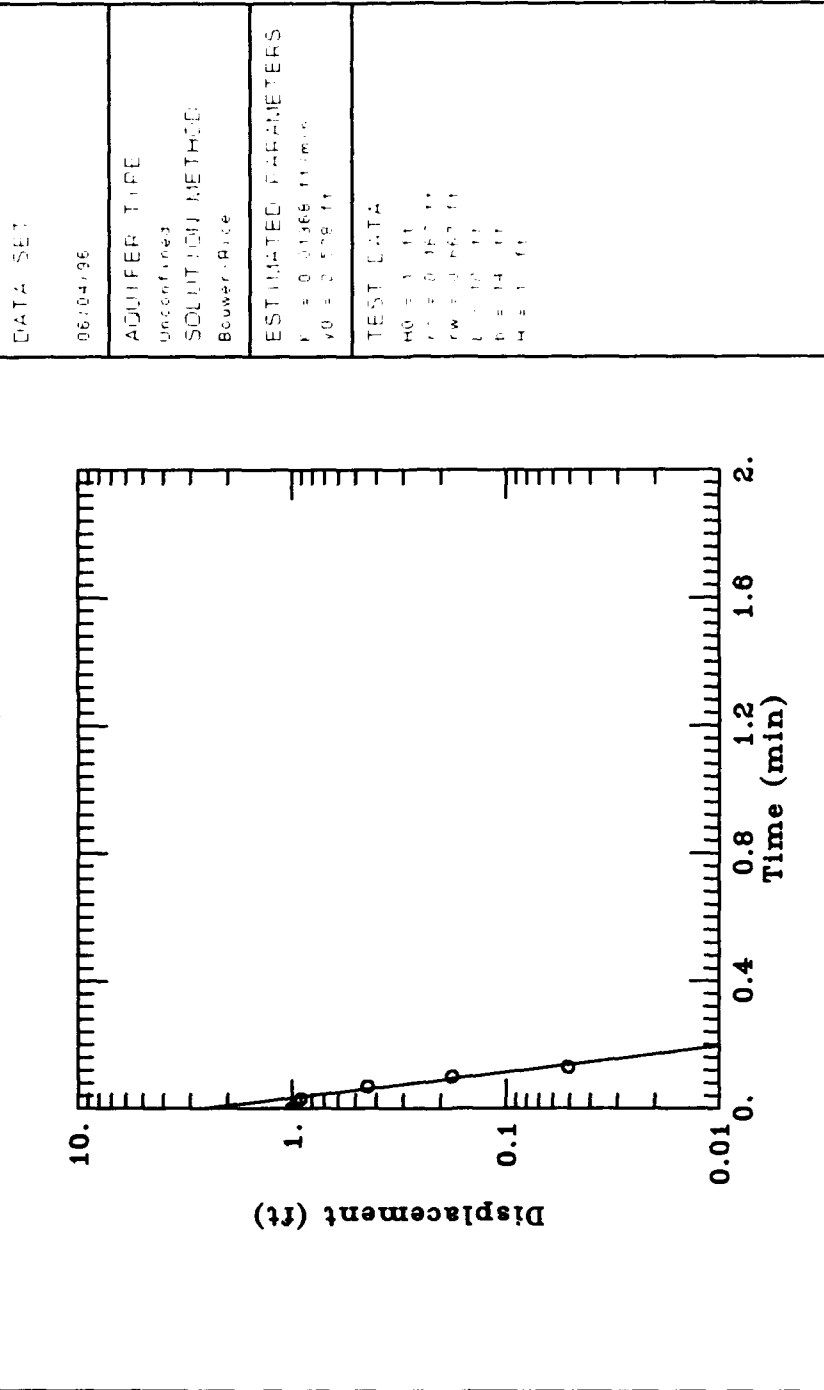
06/04/96

06/04/96

06/04/96



Bld 1212, MW-11 (Rising Head Test-1)



DATA SET	06104196
AQUIFER TYPE	unconfined
SOLUTION METHOD	Bouwer-Rice
ESTIMATED PARAMETERS	$V = 0.01368 \text{ ft}^3/\text{min}$ $V_0 = 0.008 \text{ ft}$
TEST DATA	$H_0 = 1.11$ $L = 0.067 \text{ ft}$ $r_w = 0.003 \text{ ft}$ $t = 10.11$ $D = 14.17$ $H = 1.11$

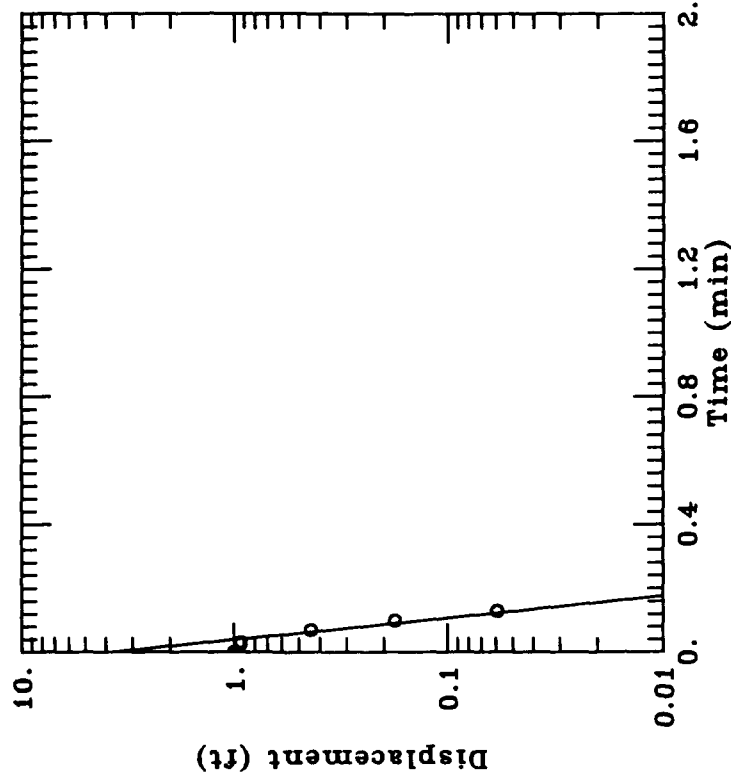
Bld 1212, MW-11 (Rising Head Test-2)

DATE: 06/04/96

ADAPTER TYPE: 06/04/96
SOLUTION METHOD: 06/04/96
BLANK RATE: 06/04/96

ESTIMATED PARAMETERS:
1. 0.0169 ft/min
2. 1.14 ft

TEST DATA:
MC 1.11
PC 0.067 ft
WC 0.067 ft
SC 0.067 ft
TC 0.067 ft
WC 0.067 ft



APPENDIX B

SOIL AND GROUNDWATER ANALYTICAL DATA



Ref: 96-DK34/vg
July 24, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *✓*

Dear Dr. Kampbell:

This report contains the results of my GC/MSD analysis of methylene chloride core extracts from Fairchild AFB for benzene, toluene, ethylbenzene, xylenes and trimethylbenzenes under Service Request #SF-2-208.

The analytical method was a modification of RSKSOP-124. Cool (38°C), on-column injection (0.1 µl) was used with a constant flow of 0.9 ml/min. A 30M X 0.25 mm Restek Stabilwax (Crossbonded Carbowax-PEG, 0.5 µm film) capillary GC column with 9 inch X 0.53 mm uncoated capillary precolumn was used. Quantitation was based on calibration curves of target ions (SIM mode) for each compound chosen from those listed in EPA method 524.2 Revision 3.0. Calibration curve range was 0.05-250 ug/ml. Complete reports detailing the acquisition methods and calibration curves have been recorded. The samples were extracted June 4, 1996 and analyzed July 10, 1996.

If you require further information, please feel free to contact me.

Sincerely,

David A. Kovacs
David A. Kovacs

xc: R.L. Cosby
G.B. Smith
J.L. Seeley *✓*
J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	Benzene	Toluene	EB	p-X	m-X	o-X	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
PES-MW1-8'	BLQ	4.47E-01	6.55E+00	8.65E+00	1.71E+01	1.06E+01	5.60E+00	1.86E+01	4.31E+00
PES-MW3-9'	4.75E-02	1.57E-01	1.75E-01	1.87E-01	1.95E-01	1.92E-01	1.09E-01	2.71E-01	5.72E-02
PES-MW3-20.5'	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
PES-MW4-10.5'	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
PES-MW5-9'	ND	3.85E-02	4.57E-01	6.47E-01	6.17E-01	2.80E-01	8.05E-01	2.02E+00	3.33E-01
PES-MW6-9'	ND	BLQ	ND	BLQ	BLQ	ND	ND	ND	ND
PES-MW7-8.5'	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
PES-MW8-8.5'	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
PES-MW12-8.5'	6.15E-02	BLQ	4.35E-02	BLQ	BLQ	ND	ND	ND	ND
Method Blank 6-4-96	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
<u>Check Standards (ug/ml)</u>									
	Benzene	Toluene	EB	p-X	m-X	o-X	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
250	2.71E+02	2.68E+02	2.67E+02	2.69E+02	2.70E+02	2.69E+02	2.69E+02	2.69E+02	2.69E+02
50	4.87E+01	4.87E+01	4.92E+01	4.90E+01	4.81E+01	4.85E+01	4.87E+01	4.84E+01	4.83E+01
5	5.42E+00	5.41E+00	5.41E+00	5.39E+00	5.45E+00	5.37E+00	5.41E+00	5.41E+00	5.41E+00
5	4.41E+00	4.43E+00	4.48E+00	4.50E+00	4.35E+00	4.52E+00	4.46E+00	4.46E+00	4.46E+00
0.5	4.52E-01	4.68E-01	4.63E-01	4.63E-01	4.49E-01	4.60E-01	4.59E-01	4.63E-01	4.58E-01
Methylene Chloride	ND	ND	ND	ND	ND	ND	ND	ND	ND
QC #1 5ppm	5.08E+00	N/A	5.07E+00	4.88E+00	4.65E+00	4.85E+00	N/A	N/A	N/A
QC #2 250ppm	N/A	2.48E+02	N/A	2.75E+02	2.75E+02	2.71E+02	2.79E+02	N/A	N/A

BLQ < 0.05 ug/ml

Analyst: David A. Kovacs

7/23/96 Page 1 of 1



Ref: 96\LB45

June 20, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Please find attached the analytical results for Service Request SF-2-208 requesting the analysis of Fairchild AFB groundwater samples to be analyzed by purge-and-trap/GC-FID:PID for Benzene, Toluene, Ethylbenzene, p-, m-, & o-Xylene, 1,3,5-, 1,2,4-, & 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We obtained the 17 groundwater samples, all but one in duplicate, in capped, 40 mL VOA autosampler vials on June 6, 1996, and they were analyzed on June 6, 1996. The samples were acquired and processed using the Millennium data system. A 5 place (1-1000 ppb) external standard curve was used to quantitate sample concentration for the compounds of interest.

RSKSOP-133, "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Lisa R. Black
Lisa R. Black

xc: R.L. Cosby
G.B. Smith
J.T. Wilson
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample Name	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
1 PPB	1.0	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	N/A
QC, OBSERVED, PPB	49.6	48.3	54.1	49.0	50.2	50.1	51.4	52.6	54.2	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A
FFT-GPC	229	273	616	968	2823	312	282	799	434	8298
FMW-GP1	BLQ	BLQ	ND	ND	BLQ	ND	ND	ND	ND	BLQ
FMW-GP2	BLQ	BLQ	ND	ND	BLQ	BLQ	ND	ND	ND	BLQ
FMW-Tank	*1.7	BLQ	ND	ND	ND	34.1	BLQ	ND	5.1	161
FMW-Tank Duplicate	*1.7	BLQ	ND	ND	BLQ	35.5	BLQ	ND	5.6	180
FMW-1D	109	371	415	1236	2529	1829	388	1480	433	10500
FMW-1S	291	673	892	2437	4909	3916	504	1953	697	16300
FMW-2	ND	ND	ND	BLQ	BLQ	BLQ	ND	BLQ	ND	BLQ
FMW-3	190	447	559	750	679	797	267	774	238	7097
FMW-4	BLQ	BLQ	1.1	1.4	2.4	1.4	BLQ	1.9	1.2	61.0
FMW-5	6.8	141	523	728	708	428	338	1010	238	9530
100 PPB	109	106	108	108	108	107	109	111	111	N/A
FMW-6	149	15.7	157	194	91.7	265	77.9	263	112	2130
FMW-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-11 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-12	25.3	BLQ	BLQ	BLQ	ND	2.3	4.9	ND	4.3	93.2
QC, OBSERVED, PPB	50.7	48.3	53.5	23.8	49.0	50.0	50.3	51.4	52.7	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A

* FID value used due to peak interference on PID

ND = None Detected; N/A = Not Analyzed; BLQ = Below Limit of Quantitation, 1 ppb

MANTECH

Ref: 96-DF37

June 18, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *20f for SA*

Dear Don:

As requested in Service Request SF-2-208, GC/MS analysis for base/neutral extractable semi-volatile compounds was done on one water sample from the Fairchild AFB labeled FMW-1D. The sample was received on June 3, 1996. Extraction of the samples was done by Mark Blankenship on June 4, 1996. The extract was analyzed by GC/MS on June 14, 1996. EPA method 8270A with the modifications listed below was used for this analysis.

After the pH of one liter of each water sample was adjusted to slightly above 11.0 with 10N NaOH, it was extracted three times with 60 ml aliquots of methylene chloride. After the methylene chloride fraction was passed through a Na₂SO₄ column, it was concentrated using the Savant Concentrator to a final volume of 1.0 ml.

For qualitative analysis, the Hewlett Packard 7673 auto-injector delivered 1.0 µl of the methylene chloride extract of sample FTA-2-95 with splitless injection to a 60 meter, 0.25 mm DB5-MS capillary column with 0.25 µm film thickness. The column was temperature programmed from 40°C to 100°C at 30°C/min and then to 300°C at 6°C/min. The Finnigan 4615 GC/MS was scanned from 39 to 650 m/z in 0.5 sec.

Attached please find chromatograms of the base/neutral extract of the Fairchild sample. The extract contained high levels of the aromatic compounds ranging from xylenes to methyl

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

naphthalenes. Three dimethylphenols and two benzenemethanol compounds were also found in the extract.

If you should have any questions, please feel free to contact me.

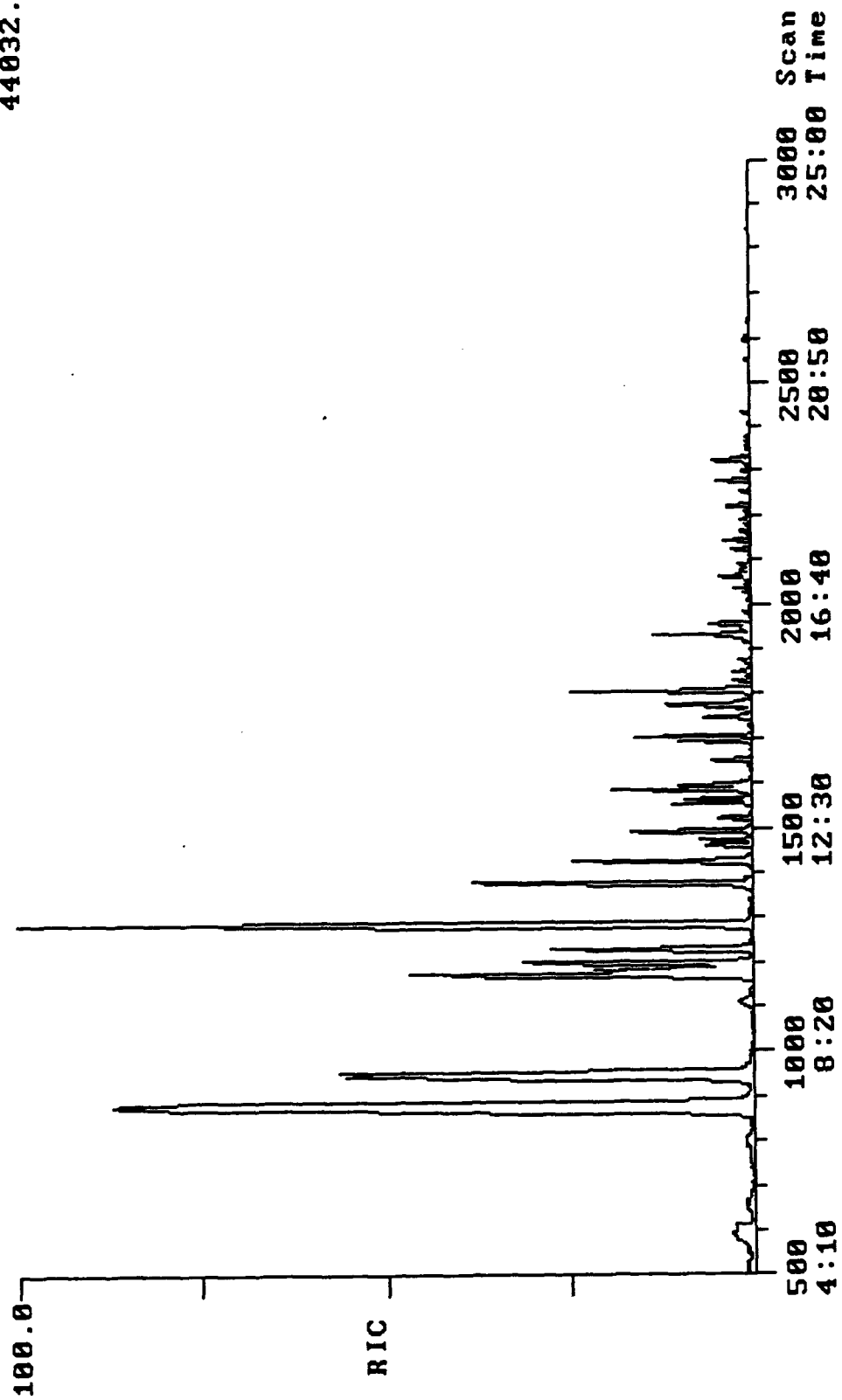
Sincerely,

Dennis D. Fine

Dennis D. Fine

xc: J. Seeley *JS*
G. Smith
R. Cosby
D. Fine

RIC
06/14/96 6:30:00
Data: 19FMW1DB #1
Cal: CAL613 #3
Sample: 1UL B/N EXT FAIRCHILD AFB FMW-1D NO DILUTION
Conds.: 40C TO 300C 6C/MIN SPLITLESS 1MIN DB5MS60.25.25
Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
44032.



RIC

06/14/96 6:30:00

Data: 19FMW1DB #1

Scans 500 to 1000

Cal: CAL613 #3

Sample: 1UL B/N EXT FAIRCHILD AFB FMW-1D NO DILUTION

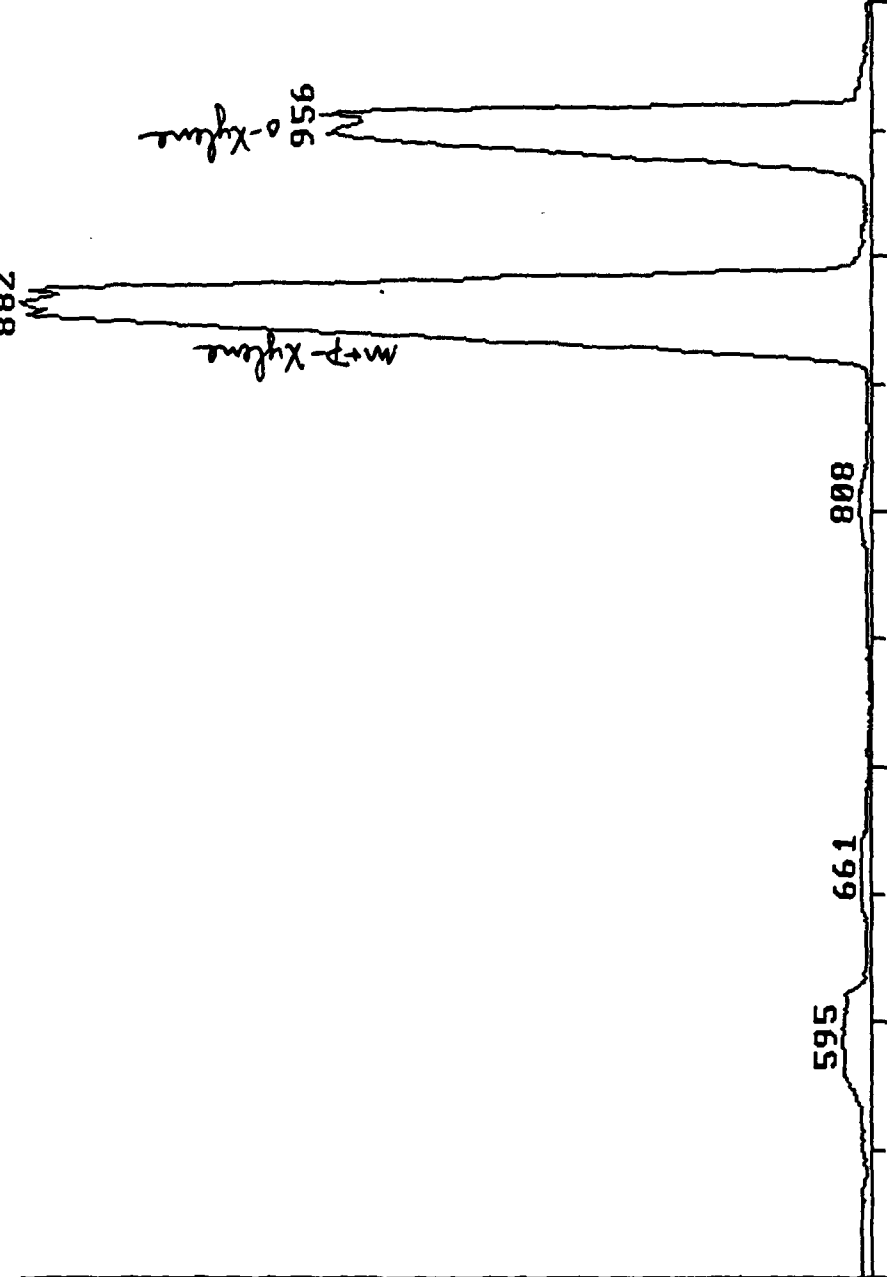
Conds.: 40C TO 300C 6C/MIN SPLITLESS 1MIN DB5MS60.25.25

Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3

100.0

882

38400.



595

661

808

500
4:10

600
5:00

700
5:50

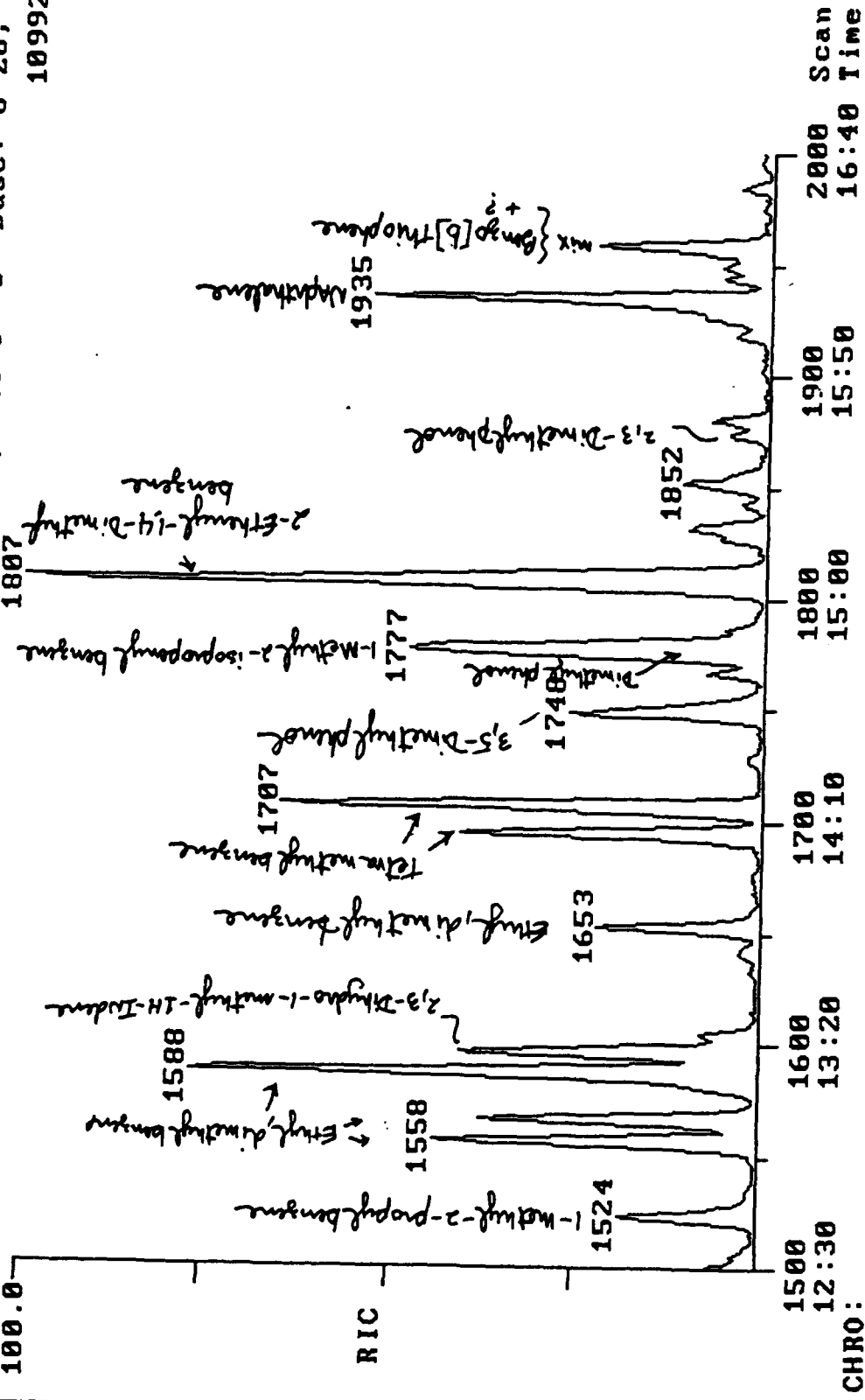
800
6:40

900
7:30

1000
8:20

CHRO:

RIC
 06/14/96 6:30:00
 Data: 19FMW1DB #1805
 Cali: CAL613 #3
 Sample: 1UL B/N EXT FAIRCHILD AFB FMW-1D NO DILUTION
 Conds.: 40C TO 300C 6C/MIN SPLITLESS 1MIN DB5MS60.25.25
 Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 100.0 10992.



RIC

06/14/96 6:30:00

Sample: 1UL B/N EXT FAIRCHILD AFB FMW-1D NO DILUTION

Conds.: 40C TO 300C 6C/MIN SPLITLESS 1MIN DB5MS60.25.25

Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3

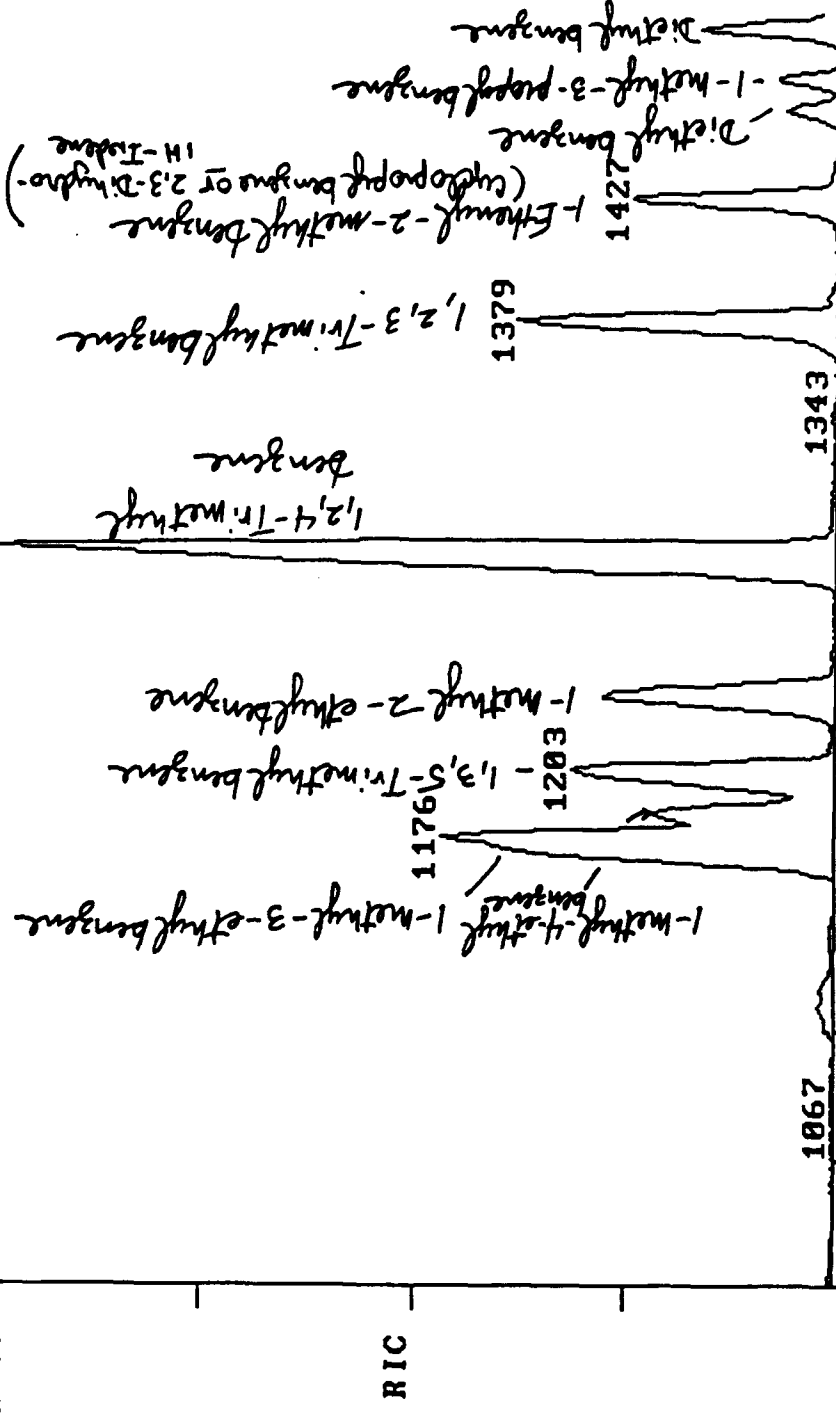
100.0

Data: 19FMW1DB #1

Cal: CAL613 #3

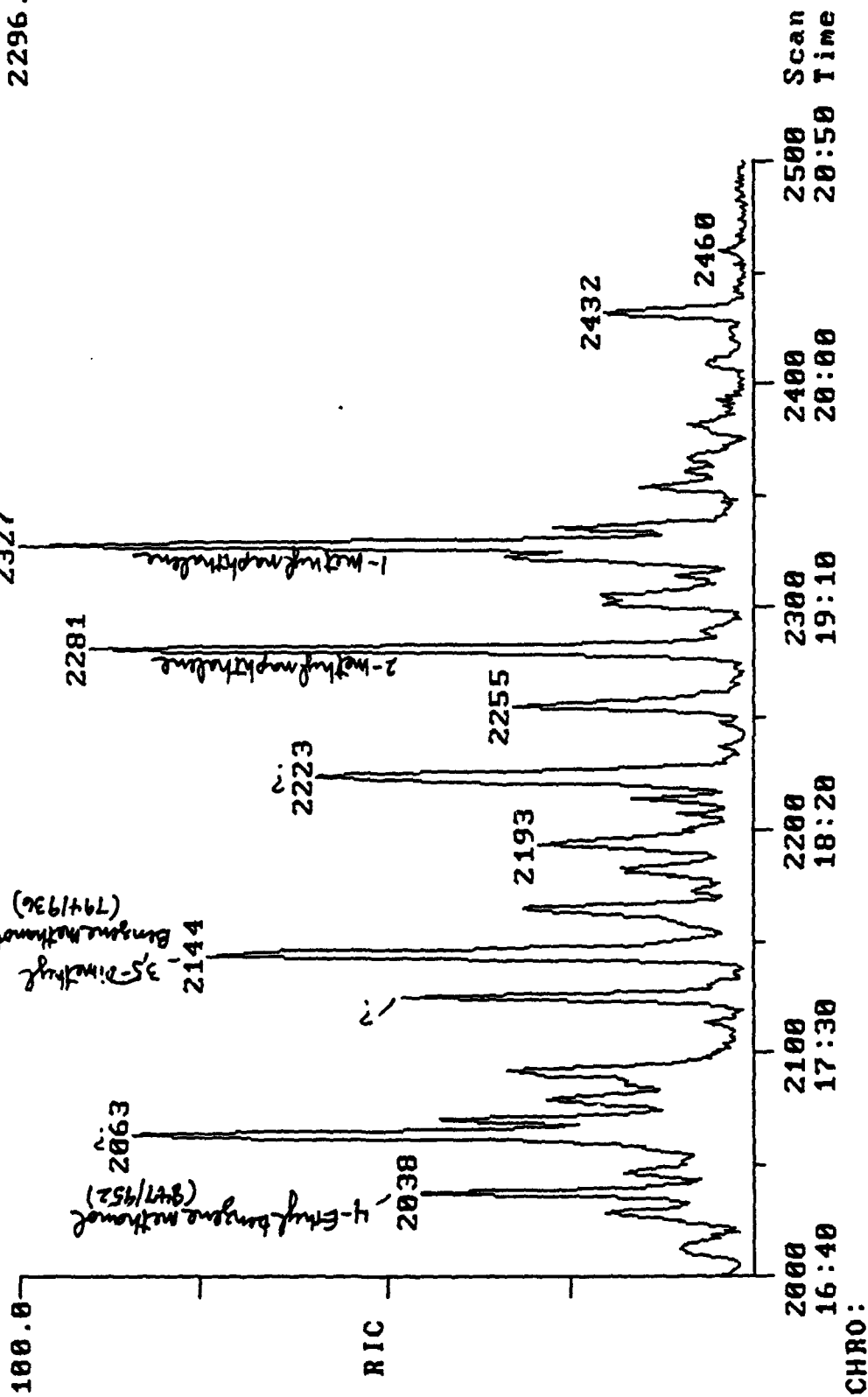
Scans 1000 to 1500

1290



44032.

RIC
 06/14/96 6:30:00
 Sample: 1UL B/N EXT FAIRCHILD AFB FMW-1D NO DILUTION
 Conds.: 40C TO 300C 6C/MIN SPLITLESS 1MIN DB5MS60.25.25
 Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 100.0
 Data: 19FMW1DB #1
 Cali: CAL613 #3
 Scans 2000 to 2500
 2327
 2296.



Fairchild AFB

MANTECH
TECHNOLOGY

Ref: 96-SH55/vg

June 7, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift^{SV}

Dear Don:

Attached are TOC results for 14 Fairchild liquids submitted June 6, 1996 under Service Request #SF-2-208. Sample analysis was begun June 6, 1996 and completed June 6, 1996 using RSKSOP-102 and RSKSOP-120.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,


Sharon Hightower

xc: R.L. Cosby

G.B. Smith

J.L. Seeley *yz*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL FAIRCHILD LIQUIDS SF-2-208

SAMPLE	MG/L TOC
--------	----------

FFT-GPC	48.9
FMW-2	1.27
FMW-3	5.71
FMW-4	9.90
FMW-5	5.98
FMW-6	14.4
FMW-7	2.67
FMW-8	6.50
FMW-8 DUP	6.74
FMW-9	2.16
FMW-10	2.53
FMW-11	2.92
FMW-12	3.55
FMW-1D	11.0
FMW-15	13.1
WPO34-I	19.22

WPO34-I std. t.v.=19.0

FAIRCHILD AIR FORCE BASE
BUILDING 1212 SITE

5-29-96

Sample	TOC ft.	D.O. mg/L	Redox mV	pH	Sulfide mg/L	Ferrous Iron mg/L	Alk. mgCaCO ₃ /L	Well
FMW-9	6.5	7.2	+120	7.06	<.1	<.1	640	2" clear
FMW-10	6.1	3.7	+119	6.94	<.1	<.1	580	2" clear
FMW-11	5.6	1.3	+116	6.77	<.1	<.1	620	2" clear
FMW-7	7.20	7.5	+110	6.78	<.1	<.1	580	2" clear
FMW-8	12.4	7.3	+74	7.16	ND	ND	ND	2" muddy
FMW-4	8.87	8.0	+94	6.73	<.1	<.1	620	2" clear
FMW-12	10.4	8.7	+87	7.02	<.1	<.1	340	2" clear
FMW-6	7.34	1.1	+5.0	6.67	<.1	3.2	1160	2" turbid
FMW-5	6.64	0.8	-121	6.40	0.2	0.9	440	2" clear
FMW-15	6.7	6.4	+30	6.87	<.1	<.1	920	2" clear
FMW-3	ND	0.7	-3.9	6.58	0.1	3.0	540	2" turbid

5-30-96

FMW-1D	ND	4.2	+149	6.85	<.1	<.1	560	2" clear
FMW-2	ND	8.9	+91	7.32	<.1	<.1	440	2" clear
FMW-GP1	ND	8.3	ND	9.1	ND	ND	ND	hole muddy
FMW-GP2	ND	6.9	ND	7.6	ND	ND	ND	hole muddy BTEXXBTM only
FFT-GPC	ND	0.5	-97	7.1	0.2	20.5	1260	GP-turbid



Ref: 96-TH34/vg
96-LP68/vg
96-JD25/vg
June 11, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Attached are the results of 14 Fairchild AFB samples submitted to MERSC as part of Service Request #SF-2-208. The samples were received June 4, 1996 and analyzed June 5, 1996. The methods used for analysis were EPA Methods 353.1 for NO₂ and NO₃, 120.1 for Conductivity and Waters capillary electrophoresis Method N-601 for Cl and SO₄. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Tim Hensley by *JKP*
Tim Hensley

Lynda Pennington
Lynda Pennington

Justin Daniel
Justin Daniel by *JKP*

xc: R.L. Cosby
G.B. Smith
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	mg/l NO ₂ ⁻ +NO ₃ ⁻ (N)	mg/l Cl ⁻	mg/l SO ₄ ⁻²	μS/Cm ³ Cond.
FFT-GPC	<.05	3.25	<.5	542
FMW-1D	.08	5.91	6.87	340
FMW-1S	<.05	8.85	6.86	524
FMW-1S Dup	<.05	----	----	----
FMW-2	8.42	103	24.4	668
FMW-3	.27	53.9	8.02	553
FMW-4	.23	7.82	18.1	406
FMW-5	<.05	4.21	3.63	269
FMW-5 Dup	----	4.16	3.60	----
FMW-6	.08	16.0	18.4	621
FMW-6 Dup	----	----	----	620
FMW-7	.26	6.49	13.6	380
FMW-7 Dup	.27	----	----	----
FMW-8	1.72	7.85	59.8	396
FMW-9	2.11	8.02	25.1	424
FMW-10	1.35	6.87	30.7	383
FMW-11	.92	6.32	5.37	392
FMW-12	.62	10.4	21.3	266
Blank	<.05	<.5	<.5	1
AQC	.38	56.3	52.2	
AQC T.V.	.39	56.0	52.0	
Spike Rec.	99%	101%	103%	



Ref: 96-JH59/vg

June 10, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Find attached results for methane and ethylene on samples received June 3, 1996 from Fairchild under Service Request #SF-2-208. Samples were prepared and calculations done as per RSKSOP-175. Analyses were performed as per RSKSOP-147.

If you have any questions concernin this data, please feel free to contact me.

Sincerely,

Jeff Hickerson
Jeff Hickerson

xc: R.L. Cosby
G.B. Smith
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SR# SF-2-208
FAIRCHILD

ANALYSIS PERFORMED 6-5-96

SAMPLE METHANE ETHYLENE

LAB BLANK	BLQ	ND
FFT-GPC	15.87	ND
FMW-1D	0.011	BLQ
FMW-1S	0.013	BLQ
FMW-2	BLQ	ND
* LAB DUP	BLQ	ND
FMW-3	0.125	ND
FMW-4	0.001	ND
FMW-5	0.060	ND
FMW-6	1.87	ND
FMW-7	0.010	ND
* FIELD DUP	0.010	ND
FMW-8	0.001	ND
FMW-9	BLQ	ND
FMW-10	BLQ	ND
FMW-11	BLQ	ND
FMW-12	BLQ	ND
* LAB DUP	BLQ	ND
10 PPM CH ₄	10.00	NA
100 PPM C ₂ H ₄	100.05	NA
1000 PPM CH ₄	1000.14	NA
1% CH ₄	1.00	NA
10% CH ₄	9.44	NA
20% CH ₄	20.26	NA
10 PPM C ₂ H ₄	NA	10.14
100 PPM C ₂ H ₄	NA	99.99

LIMITS OF QUANTITATION.

METHANE ETHYLENE

0.001 0.003

SAMPLE UNITS ARE mg/L.

STANDARDS UNITS CORRESPOND
TO THE SAMPLE COLUMN.

BLQ DENOTES BELOW LIMIT OF QUANTITATION.

ND DENOTES NONE DETECTED.

NA DENOTES NOT ANALYZED.



Ref: NV120/vg

June 10, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: J.L. Seeley *JS*

Dear Don:

Attached is the metal analysis report (4489.LST) for 4 samples (Fairchild AFB) submitted to MERSC as part of Service Request #56 under EPA Contract #68-C3-0322. The samples were received on June 3, 1996 and analyzed June 3 and 4, 1996. The samples did not received any further treatment and they were analyzed using the ICAP system. GF-AAS was used for lead determinations and results are in report PB60603.Lis;2. SOP for the ICP, GF-AAS and sample calculations were according to the procedure and instructions provided by Mr. Don Clark.

If you have any questions, please feel free to contact me.

Sincerely,

A handwritten signature in cursive script, appearing to read "Nohora Vela".

Nohora Vela

xc: R.L. Cosby
R. Puls

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

THIS REPORT (USER\$DISK:[CLARK.ICAP]LIST.LST;4489) ANALYSIS BY: ICAP (DATA.DAT)
 ELEMENTAL CONSTITUENT

PROJECT: AQ FILTERED SAMPLES. FAIRCHILD AFB.
 KAMPBELL
 SR56

CONCENTRATION IN: MG/L

14234				14235				14236				14237			
TAG NO. 14234				TAG NO. 14235				TAG NO. 14236				TAG NO. 14237			
STATION FMW-1S				STATION FMW-1D				STATION FMW-4				STATION FFT-GPC			
TIME 09:59				TIME 10:02				TIME 10:04				TIME 10:10			
DATE 04-JUN-96				DATE 04-JUN-96				DATE 04-JUN-96				DATE 04-JUN-96			
PR DIL 1.0000				PR DIL 1.0000				PR DIL 1.0000				PR DIL 1.0000			
DIL 1.0000				DIL 1.0000				DIL 1.0000				DIL 1.0000			
ELEMENT	VALUE	STDV +/-		VALUE	STDV +/-			VALUE	STDV +/-			VALUE	STDV +/-		LOD
Na-1	13.1	1.3		13.5	1.3			30.5	3.0			17.3	1.7		0.0703
K	6.55	0.66		4.21	0.44			7.75	0.80			9.38	0.92		0.2983
Ca	71.6	7.1		42.1	4.2			39.5	3.9			66.3	6.6		0.0000
Mg	20.0	2.0		11.8	1.1			9.55	0.95			23.2	2.3		0.0241
Fe	<0.0036	0.0036		0.099	0.010			0.0222	0.0035			26.3	2.6		0.0035
Mn	2.73	0.27		1.32	0.13			0.259	0.025			3.92	0.39		0.0007
Co	0.0074	0.0036		0.0053	0.0036			0.0078	0.0036			0.0091	0.0036		0.0036
Mo	<0.020	0.020		<0.020	0.020			<0.020	0.020			<0.020	0.020		0.0202
Al	<0.019	0.019		<0.019	0.019			0.063	0.019			0.045	0.019		0.0191
As	<0.010	0.010		<0.010	0.010			0.0203	0.0099			0.058	0.012		0.0099
Se	<0.016	0.016		<0.016	0.016			<0.016	0.016			<0.028	0.028		0.0160
Cd	<0.0021	0.0021		<0.0021	0.0021			<0.0021	0.0021			0.0032	0.0021		0.0021
Be	<0.0015	0.0015		<0.0014	0.0014			<0.0014	0.0014			<0.0015	0.0015		0.0014
Cu	0.0144	0.0048		0.0146	0.0047			0.0262	0.0047			0.0550	0.0049		0.0047
Cr	<0.0011	0.0011		<0.0011	0.0011			<0.0011	0.0011			<0.0011	0.0011		0.0011
Ni	0.0119	0.0031		0.0053	0.0031			0.0046	0.0031			0.0116	0.0031		0.0031
Zn	0.0007	0.0006		<0.0006	0.0006			0.0016	0.0006			0.0123	0.0018		0.0006
Ag	<0.0071	0.0071		<0.0071	0.0071			0.0131	0.0071			0.0110	0.0071		0.0071
Tl	<0.0097	0.0097		<0.0096	0.0096			<0.0096	0.0096			0.0001	0.0098		0.0096
Pb	<0.0082	0.0082		<0.0082	0.0082			<0.0082	0.0082			0.0008	0.0082		0.0082
Sr	0.497	0.049		0.229	0.023			0.319	0.032			0.492	0.049		0.0002
V	<0.010	0.010		<0.010	0.010			0.014	0.010			0.001	0.010		0.0103
Ba	0.278	0.028		0.106	0.010			0.133	0.013			0.203	0.020		0.0005
B	0.0300	0.0030		0.0024	0.0016			0.0106	0.0016			0.0144	0.0020		0.0015
Ti	<0.0019	0.0019		<0.0019	0.0019			<0.0019	0.0019			<0.0019	0.0019		0.0019

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
 RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS
 EPA/RSKRL/ADA, OK

ANALYSIS BY: ICAP (DATA.DAT)
GENERATED FROM USER\$DISK: [CLARK.ICAP]OUTPUT.DAT;3041

ELEMENTAL CONSTITUENTS
THIS REPORT (USER\$DISK: [CLARK.ICAP]LIST.LST;4489)

PROJECT: AQ FILTERED SAMPLES. FAIRCHILD AFB.
KAMPBELL
SR56

CONCENTRATION IN: MG/L

TAG NO. IECHK2		ZSTD5			
STATION		-----			
13:11		13:13			
DATE		04-JUN-96			
PR DIL		1.0000			
DIL		1.0000			
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	0.772	0.078	0.444	0.070	0.0703
K	<0.41	0.41	<0.30	0.30	0.2983
Ca	292.	29.	0.0162	0.0076	0.0000
Mg	252.	25.	<0.24	0.24	0.0241
Fe	0.0100	0.0096	97.4	9.7	0.0035
Mn	0.0102	0.0028	97.2	9.7	0.0007
Co	0.024	0.011	0.0039	0.0036	0.0036
Mo	0.021	0.020	<0.020	0.020	0.0202
Al	<0.12	0.12	96.9	9.7	0.0191
As	0.078	0.042	<0.19	0.19	0.0099
Se	0.036	0.016	<0.11	0.11	0.0160
Cd	0.0163	0.0022	0.0033	0.0021	0.0021
Be	<0.010	0.010	0.0029	0.0014	0.0014
Cu	0.058	0.012	0.0141	0.0062	0.0047
Cr	0.0088	0.0012	<0.0013	0.0013	0.0011
Ni	0.0209	0.0037	<0.0031	0.0031	0.0031
Zn	<0.0028	0.0028	<0.0015	0.0015	0.0006
Ag	<0.026	0.026	<0.0073	0.0073	0.0071
Tl	0.88	0.81	<0.063	0.063	0.0096
Pb	0.0284	0.0092	<0.053	0.053	0.0082
Sr	0.0014	0.0005	<0.0002	0.0002	0.0002
V	17.8	1.7	0.011	0.010	0.0103
Ba	0.0163	0.0015	0.0008	0.0005	0.0005
B	0.0179	0.0023	<0.0068	0.0068	0.0015
Tl	38.5	3.8	<0.0019	0.0019	0.0019

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS
EPA/RSKRL/ADA, OK

APPENDIX C

MODEL CALCULATIONS AND INPUT

**MEAN ERROR, MEAN AVERAGE ERROR, AND ROOT-MEAN-SQUARE
ERROR FOR THE CALIBRATED FLOW MODEL**

BUILDING 1212

REMEDATION BY NATURAL ATTENUATION

FAIRCHILD AFB, WASHINGTON

Location	Actual Water Level (h_m) ^{a/}	Calibrated Water Level (h_s) ^{a/}	$h_m - h_s$	$\text{abs}(h_m - h_s)$	$(h_m - h_s)^2$
MW-1(S)	2425.9	2425.5	-0.39	0.39	0.15
MW-2	2423.6	2423.5	-0.11	0.11	0.01
MW-3	2425.6	2425.6	0.07	0.07	0.00
MW-4	2425.4	2425.5	0.05	0.05	0.00
MW-5	2425.9	2425.8	-0.16	0.16	0.03
MW-6	2425.0	2425.0	0.00	0.00	0.00
MW-7	2424.9	2424.6	-0.26	0.26	0.07
MW-8	2424.7	2424.8	0.12	0.12	0.01
MW-9	2424.4	2424.4	-0.01	0.01	0.00
MW-10	2424.5	2424.5	0.00	0.00	0.00
MW-11	2423.5	2423.4	-0.09	0.09	0.01
MW-12	2425.2	2425.1	-0.06	0.06	0.00
Total:	29098.5	29097.6	-0.84	1.32	0.29
			ME ^{b/} =	-0.07	
			MAE ^{c/} =	0.11	
			RMS ^{d/} =	0.16	4.7

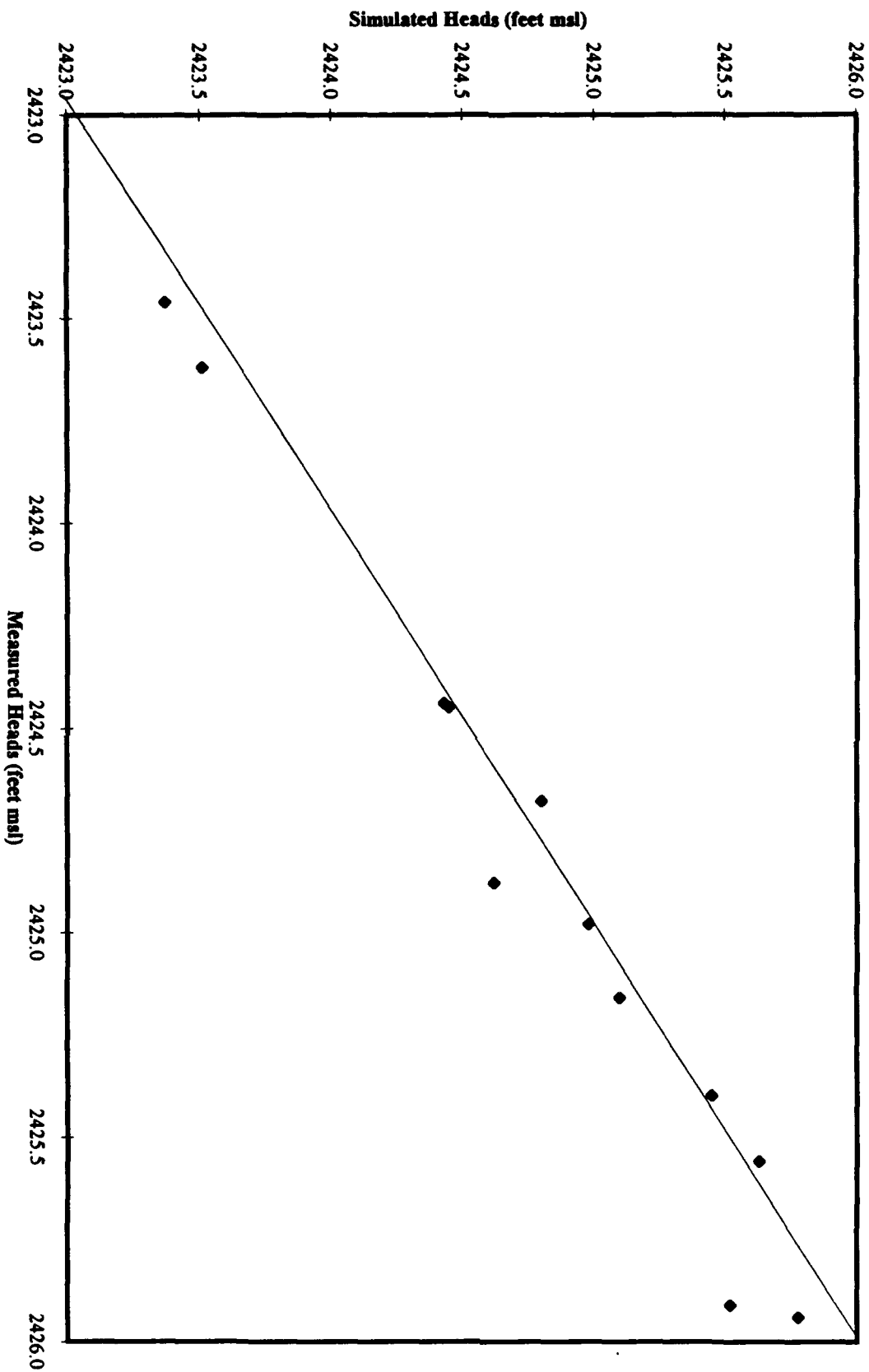
^{a/} Water levels are in feet mean-sea-level.

^{b/} ME = Mean Error = $1/n \times (h_m - h_s)$.

^{c/} MAE = Mean Average Error = $1/n \times |(h_m - h_s)|$.

^{d/} RMS = Root-Mean-Square (RMS) Error = $(1/n \times (h_m - h_s)^2)^{0.5}$.

**Measured Heads vs. Simulated Heads
Fairchild AFB, Washington**



PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE - FAIRCHILD AFB

Job No. 722450.18050

Sheet 1 of 1

Subject BUILDING 1212 - GROUNDWATER MODEL

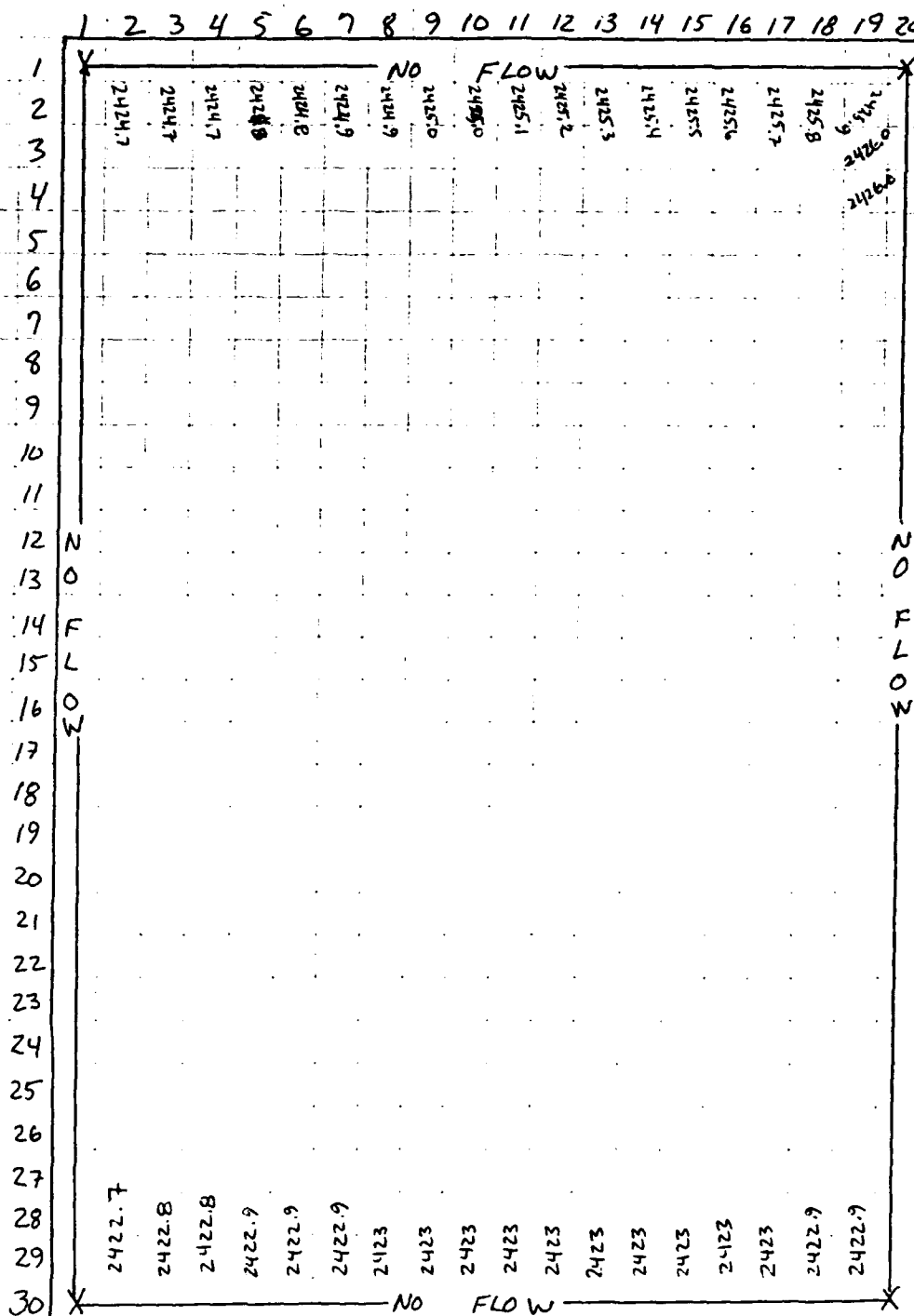
By _____

Date _____

CONSTANT HEAD CELLS

Checked _____

Rev. _____



PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE - FAIRCHILD AFB

Job No. 722450.18050

Sheet 1 of 1

Subject BUILDING 1212 - GROUNDWATER MODEL

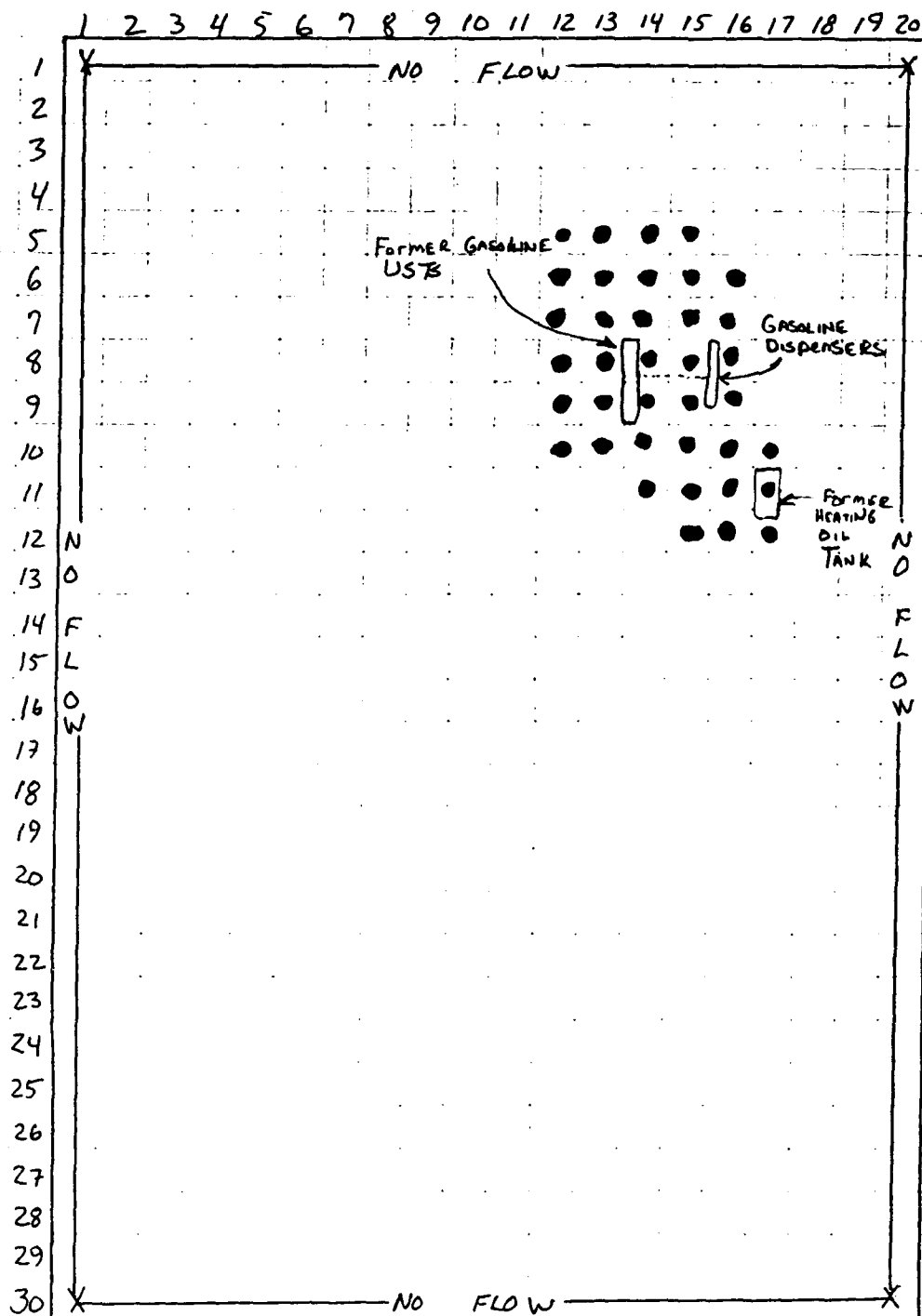
By _____

Date _____

INJECTION WELL LOCATIONS

Checked _____

Rev. _____



PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE - FAIRCHILD AFB

Job No. 722450.18050

Sheet 1 of 1

Subject BUILDING 1212 - GROUNDWATER MODEL

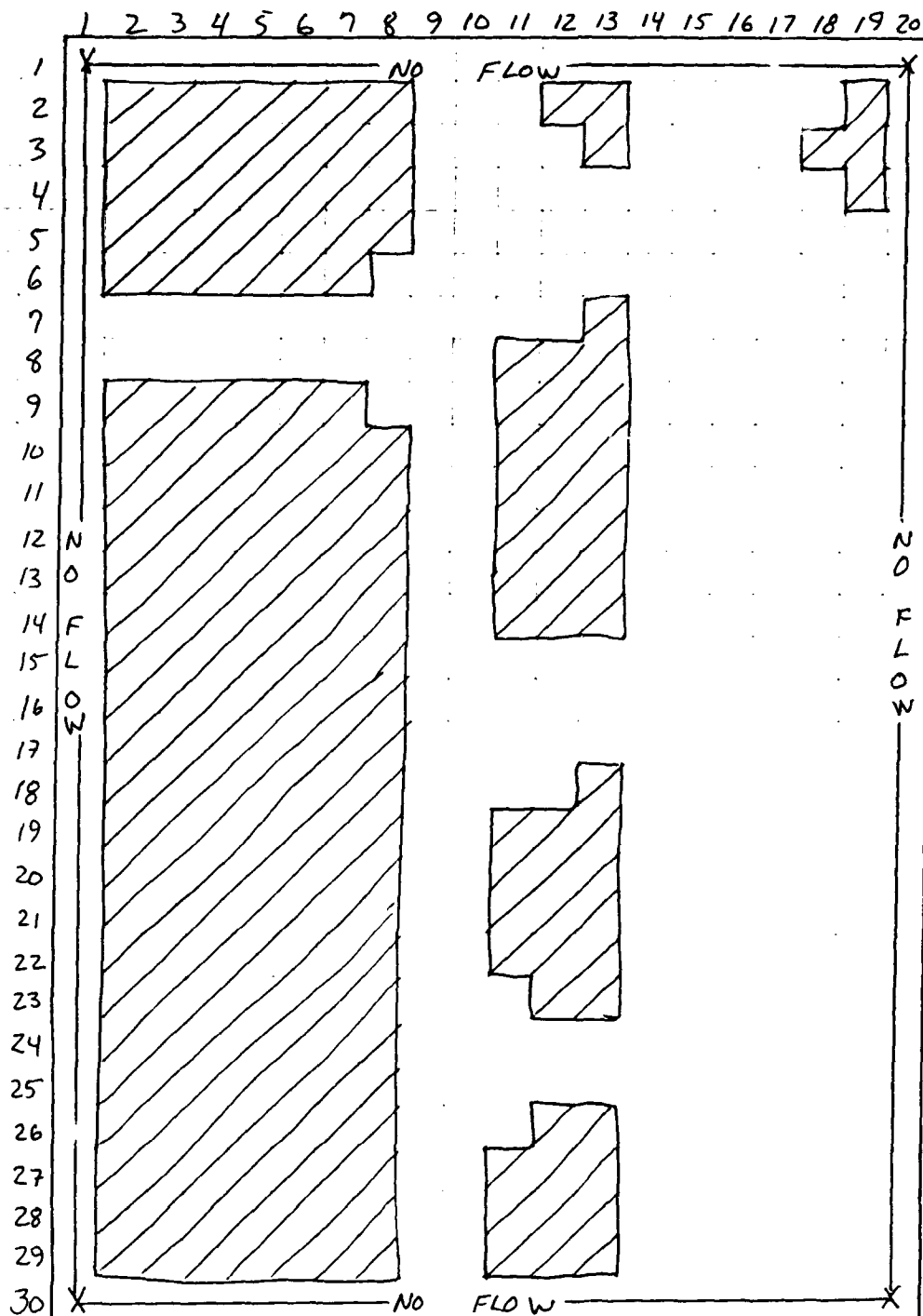
By _____

Date _____

RECHARGE WELL LOCATIONS

Checked _____

Rev. _____



Recharge Rate
 $= 1.2 \times 10^{-8}$ cfs
 $= 4.6$ in.
 yr
 $\approx 25\%$ of
 Total Precipitation

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE - FAIRCHILD AFB

Job No. 722450.18050

Sheet 1 of 1

Subject BUILDING 1212 - GROUNDWATER MODEL

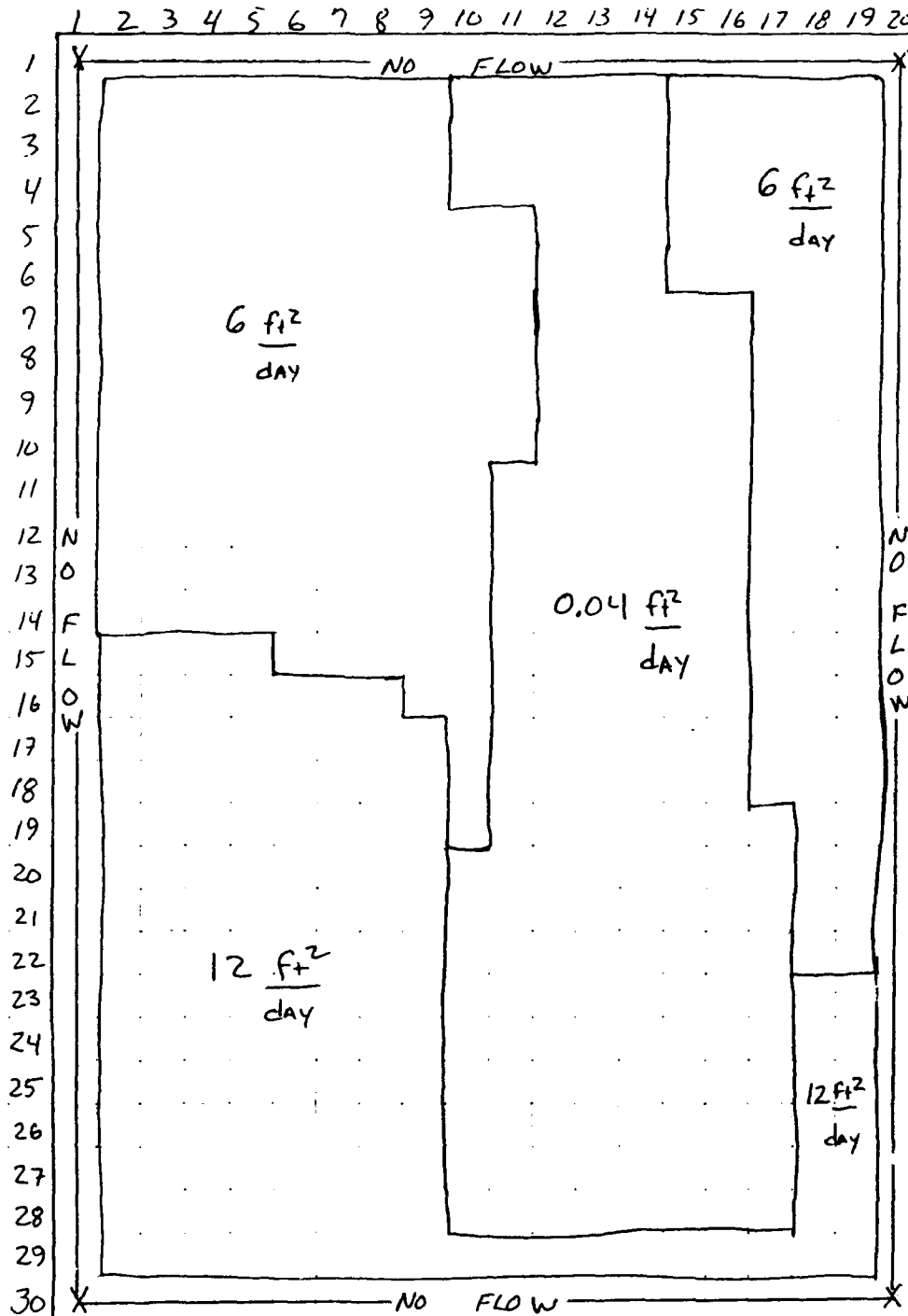
By

Date

Transmissivity Grid

Checked

Rev.



APPENDIX D

BIOPLUME II MODEL RESULTS

APPENDIX E

REMEDIAL OPTION DESIGN AND COSTING CALCULATIONS

Present Worth Analysis		Discount Factor = 7%					
Alternative 1: RNA with Institutional Controls and Long-Term Groundwater Monitoring		Present Worth (\$)	Year: 1 10 20 30 34				
Maintain Institutional Controls	34	\$32,135	\$2,500	\$2,500	\$2,500	\$2,500	\$2,500
Long-term Monitoring							
Install New Wells	1	\$15,664	\$16,761	\$0	\$0	\$0	\$0
Groundwater Sampling	34	\$49,192	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827
Reporting/Project Mgmt	34	\$70,054	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450
Subtotal Present Worth (\$)		\$167,046					

Total Present Worth Cost (\$): \$167,046

Discount Factor = 7%

Present Worth Analysis

Alternative 2: RNA, Bioventing with Institutional Controls, and Long-Term Monitoring		Cost (\$ at Year Indicated									
	years	Year: 1	2	3	4	5	6	7	8	9	
Bioventing											
Bioventing System Installation	1	\$60,399	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
System Maintenance	5	\$9,160	\$9,160	\$9,160	\$9,160	\$9,160	\$0	\$0	\$0	\$0	\$0
Annual Report	5	\$4,346	\$4,346	\$4,346	\$4,346	\$4,346	\$0	\$0	\$0	\$0	\$0
Subtotal Present Worth (\$)											
		\$111,825									
Maintain Institutional Controls											
		\$2,500	\$2,500	\$2,500	\$2,500	\$2,500	\$2,500	\$2,500	\$2,500	\$2,500	\$2,500
Long-term Monitoring											
Install New Wells	1	\$16,761	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Groundwater Sampling	9	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827
Reporting/Project Mgmt	9	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450
Subtotal Present Worth (\$)											
		\$22,394									
Total Present Worth Cost (\$):											
		\$204,219									

Present Worth Analysis			Discount Factor = 7%					
Alternative 3: RNA and Excavation with Institutional Controls and Long-Term Monitoring		Present Worth	Cost (\$) at Year Indicated					
	years	(\$)	Year: 1	2	3	4	5	6
Maintain Institutional Controls	6	\$11,916	\$2,500	\$2,500	\$2,500	\$2,500	\$2,500	\$2,500
Long-term Monitoring								
Install New Wells	1	\$15,664	\$16,761	\$0	\$0	\$0	\$0	\$0
Groundwater Sampling	6	\$18,242	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827	\$3,827
Reporting/Project Mgmt	6	\$25,978	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450	\$5,450
Subtotal Present Worth (\$)		\$71,800						
Limited Soil Excavation								
Excavation	1	\$177,202	\$189,606	\$0	\$0	\$0	\$0	\$0
		\$177,202						

Total Present Worth Cost (\$):

\$249,002

Alternatives 1, 2, and 3: Long-Term Monitoring and Institutional Controls

Standard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Install New LTM/POC Wells (\$)	Task 2 (hrs)	Sampling (\$)	Task 3 (hrs)	Reporting & PM (\$)
Word Processor 88/(15)	\$30	0	\$0	0	\$0	30	\$900
CADD Operator 58/(25)	\$47	4	\$188	0	\$0	30	\$1,410
Technician 42/(50)	\$40	5	\$200	32	\$1,280	20	\$800
Staff Level 16/(65)	\$57	24	\$1,368	32	\$1,824	40	\$2,280
Project Level 12/(70)	\$65	4	\$260	4	\$260	30	\$1,950
Senior Level 10/(80)	\$85	3	\$255	0	\$0	2	\$170
Principal 02/(85)	\$97	0	\$0	0	\$0	0	\$0
Total Labor (hrs \$)		40	\$2,271	68	\$3,364	152	\$7,510
ODCs							
Phone			\$20		\$0		\$40
Photocopy			\$10		\$0		\$100
Mail			\$100		\$300		\$50
Computer			\$200		\$0		\$400
CAD			\$20		\$0		\$200
WP			\$0		\$0		\$100
Travel			\$500		\$1,000		\$0
Per Diem			\$475		\$760		\$0
Eqpt. & Supplies			\$300		\$100		\$0
Total ODCs			\$1,625		\$2,160		\$890
Outside Services							
LTM/POC Well Installation Costs ^{a/}			\$12,700		\$0		\$0
Laboratory Fees ^{b/}		Soils	\$165	9 LTM, 4 sentry, and 2qa/qc,	\$2,130		\$0
Other: Maintain Institutional Controls			\$0		\$0		\$5,000
Total Outside Services			\$12,865		\$2,130		\$5,000

Proposal Estimate	Task 1	Task 2	Task 3
Labor	\$2,271	\$3,364	\$7,510
ODC's	\$1,625	\$2,160	\$890
Outside Services	\$12,865	\$2,130	\$5,000
Total by Task	\$16,761	\$7,654	\$13,400
Total Labor	\$13,145		
Total ODCs	\$4,675		
Total Outside Services	\$19,995		
Total Project	\$37,815		

Task 1: Install New LTM/POC Wells ^{a/} 3 Wells, 60ft @ \$70/ft, \$1200mob, \$300 soil handling for 3 wells
 Task 2: Sampling per Event (Assumes soils for the other 11 wells can be spread on-site.)

Task 3: Reporting and PM per Sampling Eve ^{b/} BTEX/VOC @ \$120ea, Electron receptors at LTM wells @ \$150ea

Alternative 2: Bioventing

Standard Rate Schedule

Category	Billing	Task 1	Design & Install	System Monitoring/	Task 3	End of Year
Cost Code/(Billing Category)	Rate	(hrs)	Biovent System (\$)	Task 2 Maintenance (2x per yr)(\$)	(hrs)	Report (\$)
Word Processor 88/(15)	\$30	40	\$1,200	0	8	\$240
CADD Operator 58/(25)	\$47	100	\$4,700	0	8	\$376
Technician 42/(50)	\$40	240	\$9,600	80	8	\$320
Staff Level 16/(65)	\$57	280	\$15,960	20	40	\$2,280
Project Level 12/(70)	\$65	100	\$6,500	10	8	\$520
Senior Level 10/(80)	\$85	8	\$680	0	2	\$170
Principal 02/(85)	\$97	1	\$97	0	0	\$0
Total Labor (hrs \$)		769	\$38,737	110	74	\$3,906
ODCs						
Phone			\$400	\$120		\$20
Photocopy			\$500	\$60		\$100
Mail			\$200	\$240		\$40
Computer			\$500	\$0		\$200
CAD			\$500	\$0		\$40
WP			\$200	\$0		\$40
Travel			\$1,000	\$1,000		\$0
Per Diem			\$1,900	\$950		\$0
Eqpt. & Supplies			\$2,000	\$400		\$0
Total ODCs			\$7,200	\$2,770		\$440
Outside Services						
Well Installation			\$5,500	\$0		\$0
System Installation			\$6,662	\$0		\$0
Equipment Costs			\$800	\$0		\$0
Electrical Costs			\$0	\$200		\$0
Laboratory Fees			\$1,500	\$1,200		\$0
Other			\$0	\$0		\$0
Total Outside Services			\$14,462	\$1,400		\$0
Estimate		Task 1	Task 2	Task 3		
Labor		\$38,737	\$4,990	\$3,906		
ODC's		\$7,200	\$2,770	\$440		
Outside Services		\$14,462	\$1,400	\$0		
Total by Task		\$60,399	\$9,160	\$4,346		
Total Labor		\$47,633				
Total ODCs		\$10,410				
Total Outside Services		\$15,862				
Total Project		\$73,905				

Task 1: Bioventing System Design and Construction
 Task 2: Monthly Site Time and Travel Costs (per year)
 Task 3: Report Preparation

Alternative 3: Soil Excavation

Standard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1	Excavation (\$)
Word Processor 88/(15)	\$30	2	\$60
CADD Operator 58/(25)	\$47	2	\$94
Technician 42/(50)	\$40	40	\$1,600
Staff Level 16/(65)	\$57	64	\$3,648
Project Level 12/(70)	\$65	20	\$1,300
Senior Level 10/(80)	\$85	1	\$85
Principal 02/(85)	\$97	0	\$0
Total Labor (hrs \$)		129	\$6,787
ODCs			
Phone			\$20
Photocopy			\$20
Mail			\$50
Computer			\$100
CAD			\$100
WP			\$50
Travel			\$1,000
Per Diem			\$475
Eqpt. & Supplies			\$200
Total ODCs			\$2,015
Outside Services			
Excavation Costs including Soil Hauling/Disposal			\$180,804
Total Outside Services			\$180,804

Proposal Estimate	Task 1
Labor	\$6,787
ODC's	\$2,015
Outside Services	\$180,804
Total by Task	\$189,606
Total Labor	\$6,787
Total ODCs	\$2,015
Total Outside Services	\$180,804
Total Project	\$189,606

Task 1: Work Plan Development

Fairchild AFB Backup Calculations

Alternatives 1, 2, and 3: Long-term Monitoring

Misc calculations		Cost calculations						
		Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Number of LTM and sentry wells:		Well Installation	ea	2	\$ 1,200	\$ 2,400	\$ 12,700	Budinger & Assoc - 1996 cost Roar Tech - 1996 cost estimate
Shallow:	3	Mobilization	drum	5	\$ 100	\$ 500		
Number of wells:	20	Soil Disposal	ln ft	60	\$ 70	\$ 4,200		
Depth each:		Shallow:	ln ft	40	\$ 140	\$ 5,600		
Basalt Bedrock:	1	Well Installation (HSA)						
Number of wells:	40	Deep (bedrock)						
Depth:		Well Installation (?)						

Fairchild AFB Backup Calculations

Alternative 2: Bioventing System						
Cost calculations						
Misc calculations	Description	Unit	Qty.	Unit Price	Subtotal	Total Source (If applicable)
Wells/Monitoring Points Number of Wells: 3 Number of MPs: 5 Depth: 10 ft	Well Installation	ea	1	\$ 1,200	\$ 1,200	Budinger & Assoc - 1996 cost
	Mobilization	In ft	30	\$ 70	\$ 2,100	
	Well Installation	In ft	50	\$ 40	\$ 2,000	
	MP Installation	In ft	2	\$ 100	\$ 200	
Trench Volume/Area Width: 8 in Depth: 1.5 ft Length: 150 ft Volume: 150 cf	Soil Disposal	drum				
	Equipment Costs					
	Blower(s)	ea	1	\$ 800	\$ 800	
Surface Area: 6 cy 100 sf 11 sy	System Installation	ea	1	\$ 1,000	\$ 1,000	Means 022 254 0050 Means 151 701 0550/026 686 2800
	Mob/Demob	cy	6	\$ 5.05	\$ 30	
	Trenching	In ft	150	\$ 13.05	\$ 1,958	
	Pipe laying	cy	-	\$ 17.20	\$ -	
	Backfill	cy	-	\$ 5.10	\$ -	
	Compaction	sy	11	\$ 5.25	\$ 58	Means 022 204 0600
	Pavement Base	cy	-	\$ 97.00	\$ -	Means 022 308 0100
	Concrete repair	sy	-	\$ 1.91	\$ -	Means 033 130 4700
	Reseeding	If	150	\$ 9.30	\$ 1,395	Means 029 304 0310
	Piping	man hr	-	\$ 38.83	\$ -	Means 151 551 1880
	Mechanical	ls	1	\$ 1,000	\$ 1,000	Means Q-1 crew
	Electrical	cy	0.2	\$ 97.00	\$ 22	Means 033 130 4700
	Slab	ea	1	\$ 1,200	\$ 1,200	Means 131 221 0010
	Blower House (including shipping)					

Fairchild AFB Backup Calculations

Alternative 3: Excavation		Cost calculations					
Misc calculations		Description	Unit	Qty.	Unit Price	Subtotal	Total
Excavation Volume/Area		Soil Excavation	cy	3,300	\$22.00	\$ 72,600	\$ 180,804
Area		Disposal & Trans.	cy	3,300	\$3.20	\$ 10,560	
Depth:		Backfill	cy	3,300	\$2.00	\$ 6,600	
Volume:		Hauling of Backfill	cy	3,300	\$16.66	\$ 54,978	
Surface Area:		Compaction	cy	3,300	\$5.10	\$ 16,830	
		Replace Asphalt & Subbase	sy	990	\$6.40	\$ 6,336	Means 022 204 0600 Means 022 204 0600 Means 022 204 0600 Means 022 308 0100
		Sampling (8015)	each	33	\$130.00	\$ 4,290	Assume one soil sample per 100 yards.
		Contingency	%	5%	\$ 172,194	\$ 8,610	

*This radius was estimated to include an area equivalent for both the north and south source area